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70-Year Statistics

Chicago Univ., IL

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Washington, DC

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If one were to count tornadoes as the Gross National Product, no other country on the surface of the earth could come even close to the United States. During the recent 70-year period, the United States produced 31,054 tornadoes which left behind a cumulative path of 132,005 miles (212,396 km) which would circle the world 5.3 times along the equator. In completing the book, staff members of the Satellite and Mesometeorology Research Project (1961 to the present) played an important role in collecting, evaluating, and archiving the historical tornado data.

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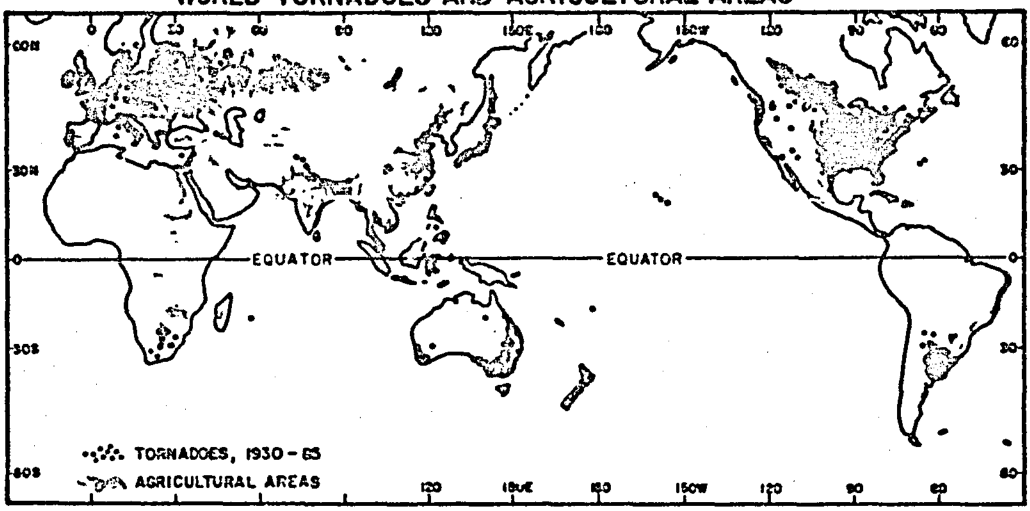
U.S. TORNADOES

Part One

70-Year Statistics

WORLD TORNADOES AND AGRICULTURAL AREAS



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U.S. Tornadoes Part 1

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PREFACE

If one were to count tornadoes as the Gross National Product, no other country on the surface of the earth could come even close to the United States. During the recent 70-year period, the United States produced 31,054 tornadoes which left behind a cumulative path of 132,005 miles (212,396 km) which would circle the world 5.3 times along the equator. According to current estimates, the United States share is 75% of the world production of tornadoes.

It is interesting to find that the agricultural areas of the world coincide very well with the regions of tornadoes. First, rich crops need the seasonal variation of temperature along with an abundant supply of moisture during their growing seasons. Second, tornado-spawning thunderstorms also need moisture which fuels the growing storms triggered and maintained by the atmospheric instability in the middle latitudes.

The other side of the coin is the adverse effect of tornadoes which could wipe out crops, damage structures, and even injure or kill people. The purpose of this book is to present the statistical fact of U.S. tornadoes, for use by various individuals and organizations in assessing the tornado hazards for future applications.

In completing this book, staff members of the Satellite and Mesometeorology Research Project (1961 to the present) played an important role in collecting, evaluating, and archiving the historical tornado data. The author wishes to express his thanks to the current staff, Messrs. Brian Smith, Eric Peterson, and Duane Stiegler for their continuing efforts on tornado research. Special thanks are due to Mr. Jaime Tecson who updated the University of Chicago Tornado Tape and generated various types of grid-print tornado maps included in this publication, and to Mr. Jim Partacz for completing the photographic charts in color.

The author is grateful to Dr. Robert Abbey, Jr. of the Office of Naval Research (ONR) who initiated the author's tornado research for nuclear power plants while he was with the Nuclear Regulatory Commission (NRC). After moving from NRC to ONR, he extended his encouragement to the author's continuing research. Publication of this book was supported in part by the Nuclear Regulatory Commission under Contract 04-82-004 being monitored by Mr. Robert Kornasiewicz.

The Fargo tornado of June 20, 1957 signaled the beginning of Fujita's tornado research at the University of Chicago. Since then, he had investigated damage areas of over 250 tornadoes, both from the air and the ground. Fujita had no chance to see a live tornado until June 12, 1932 when he observed, during the JAWS Project, an F2 tornado east of Denver, Colorado by using three Dopplar radars and ground photography.

Fujita's tornado research at the University of Chicago has been sponsored by the National Aeronautics and Space Administration under Grant NGR 14-001-008 monitored by Dr. James Dodge, by the National Environmental Satellite, Data, and Information Service under Grant NA85AADRA064, monitored by Messrs. Ralph Anderson and Linwood Whitney, and by the National Science Foundation under Grant ATM 8516705 monitored by Dr. Ronald Taylor. Without these continuing supports, the 70-year statistics of U.S. tornadoes presented in this book could not have been completed.

January 1, 1987

Tetsuya Theodore Fujita
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Born at Kitakyushu City, Japan on October 23, 1920

1953 D.Sc., Tokyo University; 1953-55 Research Associate, University of Chicago; 1955-56 Returned to Japan for an immigrant visa; 1956-62 Director of Mesometeorology Project, University of Chicago; 1962 Associate Professor of Meteorology, Director of Satellite and Mesometeorology Research Project (SMRP), University of Chicago; 1965-present Professor of Meteorology, University of Chicago; 1968 Became a U.S. citizen.

TABLE OF CONTENTS

Chapter 1	MAPPING OF U.S. TORNADOES		1
	1.1 Chicago-area tornadoes	1	
	1.2 Example of U.S. tornado map	3	
	1.3 Characteristics of subboxes	6	
Chapter 2	UNIVERSITY OF CHICAGO TORNADO TAPE		13
	2.1 The Fujita tornado scale (F scale)	13	
	2.2 The University of Chicago Tornado Tape	17	
	2.3 Occurrences and path lengths by F scale	17	
	2.4 Geographic distribution by F scale	21	
Chapter 3	LONG-TERM VARIATION		31
	3.1 Tornado occurrences in 70 years	31	
	3.2 Annual occurrences	33	
	3.3 Tornado distribution by decade	37	
Chapter 4	SEASONAL VARIATION		45
	4.1 Tornado occurrences by month	45	
	4.2 Tornado path lengths by month	48	
	4.3 Tornado distribution by month	50	
Chapter 5	DIURNAL VARIATION		63
	5.1 Hourly occurrences	63	
	5.2 Bi-hourly distribution maps	70	

Chapter 6 TORNADO OUTBREAKS 83

6.1 Tornado outbreaks 83
6.2 Tornado days by daily path length 87
6.3 Maps by daily occurrence and path length 89

Chapter 7 MAPS BY DIRECTION OF MOTION 103

7.1 Statistical direction of motion 103
7.2 Distribution by direction of motion 104

Chapter 8 TORNADO WINDSPEED BY PROBABILITY 113

8.1 Tornado probability 113
8.2 DAPPL values and windspeed areas 114
8.3 Computation and maps of maximum windspeeds 115

Summary and Conclusions 121

References 122

Chapter One

Mapping of U.S. Tornadoes

Maps of historical tornadoes are very useful in assessing tornado hazards in various parts of the country. Numerous tornado maps were published by various researchers for their purposes, ranging from simple records of the past to the estimates of tornado hazards for existing and future nuclear power plants.

1.1 Chicago-area Tornadoes

As an example of mapping historical tornadoes, the Chicago-area Tornado Map in Fig. 1.1 was prepared. Included in this map are actual paths of all tornadoes confirmed during the past 110 years, 1876 — 1985. These paths are depicted by red lines identified by their occurrence dates.

The first tornado in this map occurred on May 6, 1876, over 100 years ago, when Chicago was a city of only 500,000 people. Since then, Chicago grew into a giant city with her suburbs growing continuously in all directions away from the lake.

This map presents striking features of the Chicago-area tornadoes, which are:

(1) Tornadoes far to the south of Chicago left behind damage paths extending toward the east to east-southeast.

(2) Tornadoes just to the west of Chicago moved toward the northeasterly directions.

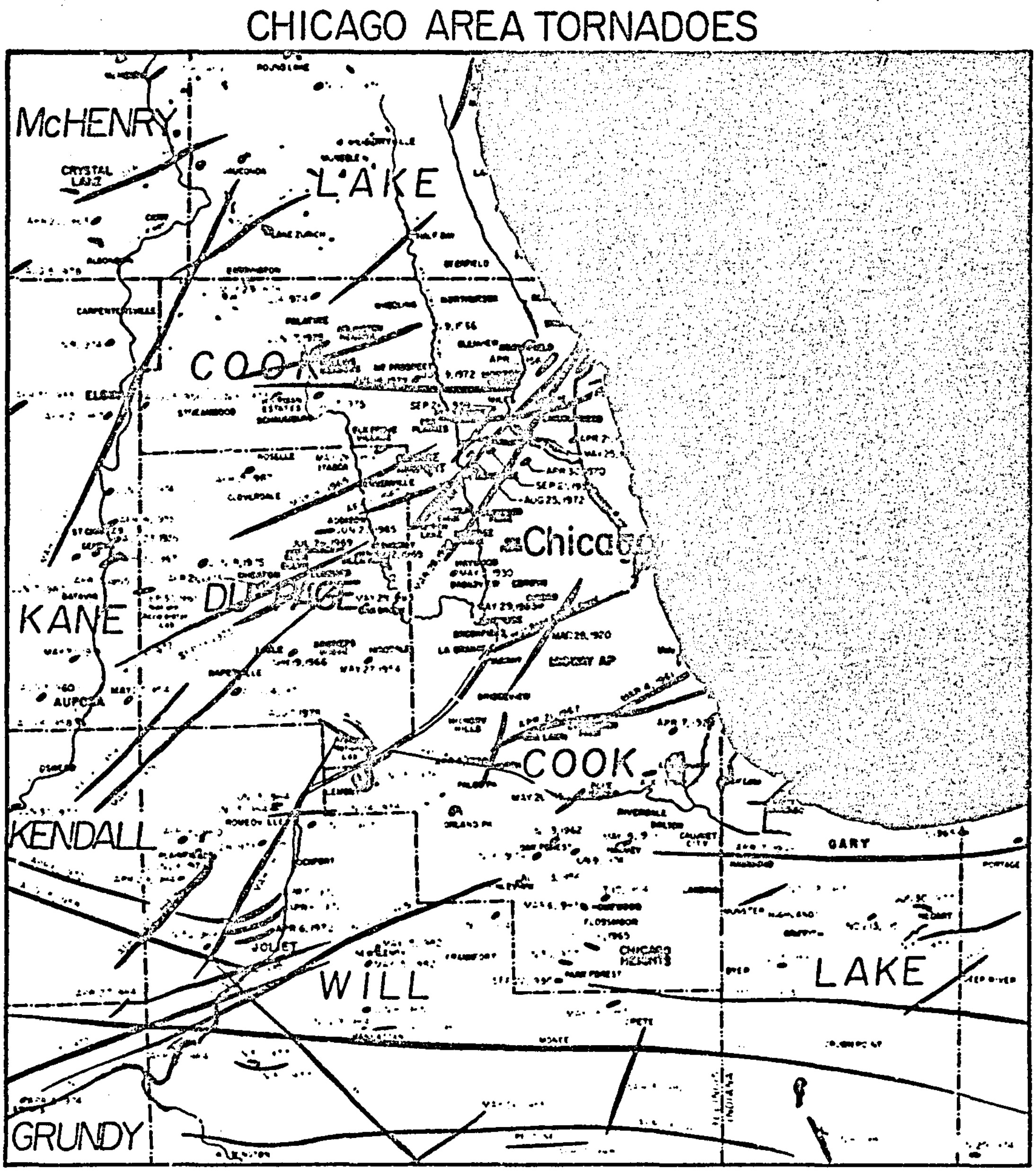


Fig. 1.1 Distribution of Chicago-area tornadoes reported during the past 100 years, 1876-1985. Shown in Lake Michigan are vectors of tornado movement in 20 minutes at various translational speeds of tornadoes.

(3) Since 1921, practically no tornadoes occurred or moved across the central portion of Chicago.

(4) There is a 10-mile-wide tornado belt extending from near Aurora to Evanston.

What did cause these tornado features has not been known yet. It has been speculated on, however, that Chicago's heat-island effects and man-made structures are acting against the tornado activity over the city.

1.2 Example of U.S. Tornado Map

It is a painstaking and time-consuming job to plot the physical paths of tornadoes covering a long period of time. it took almost three years in completing the tornado path map in Fig. 1.2 which includes 23,264 tornadoes occurring during the 49-year period, 1930-1978.

This type of tornado map is very pleasing to take a close look at and evaluate the overall patterns of tornado activities. Nonetheless, the time and effort required in producing such a physical path map are prohibitive, because we are now capable of mapping historical tornadoes by computer.

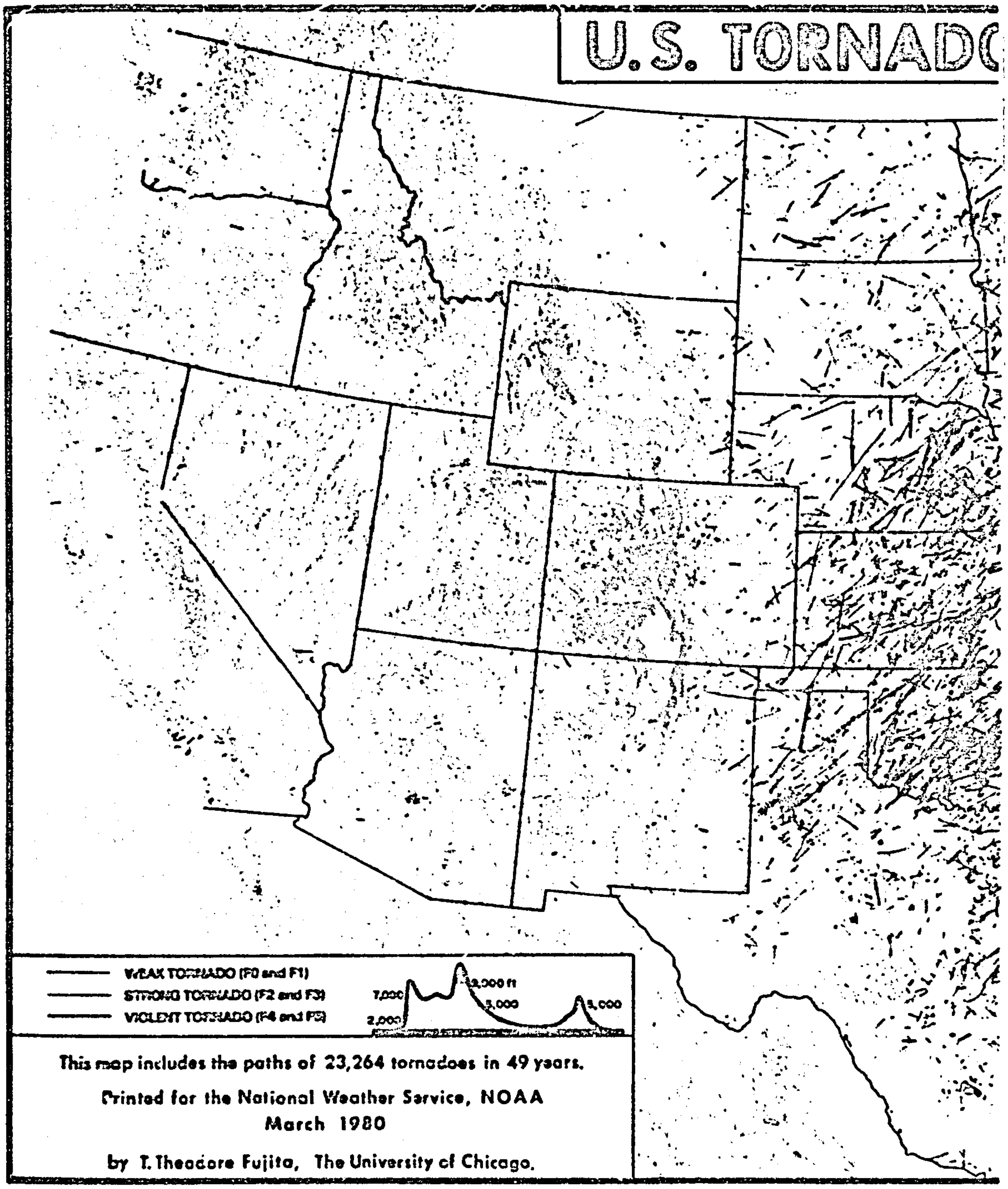
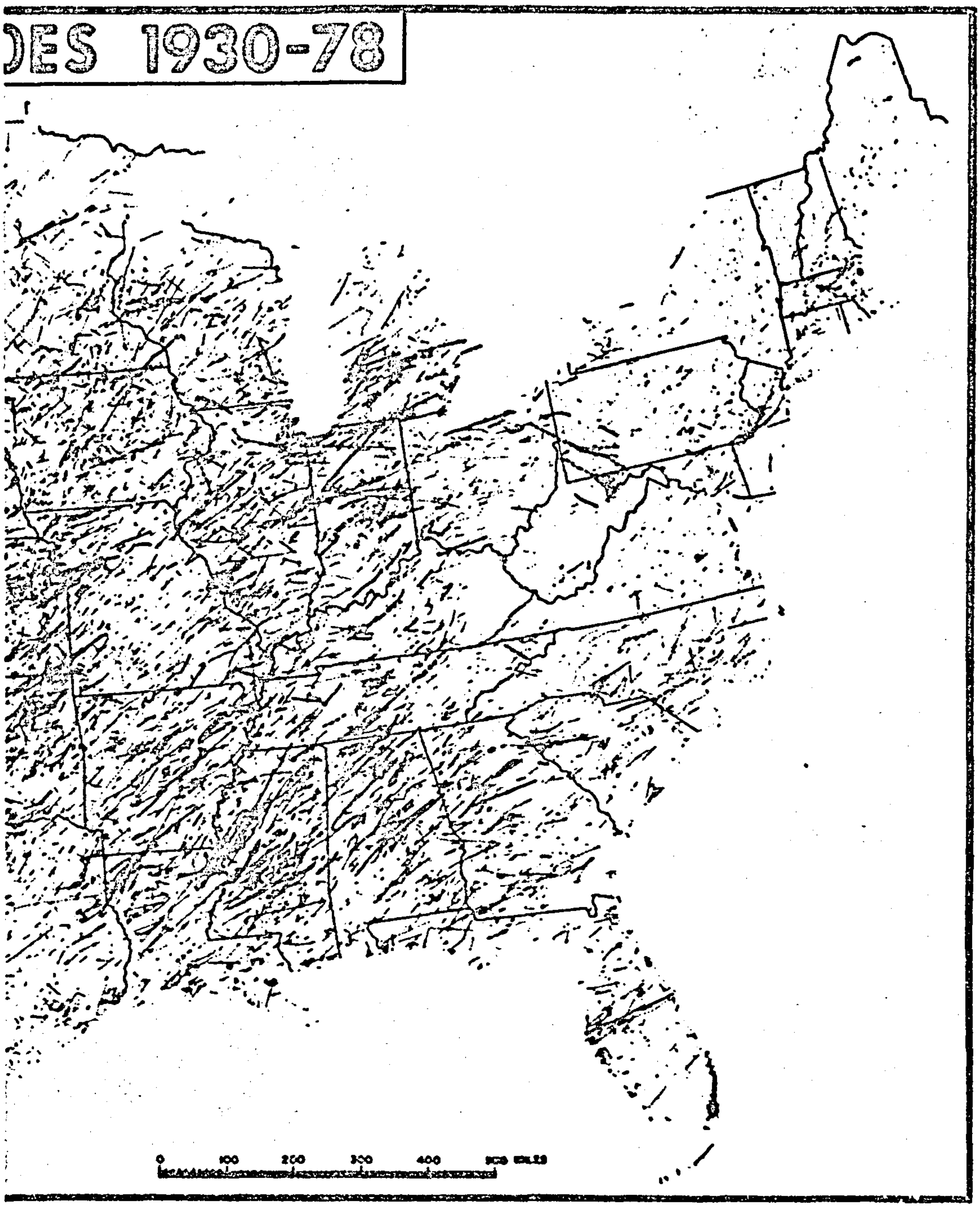


Fig. 1.2 Distribution of tornadoes during the 49-year period (1930-1978). This map was produced for the National Weather Service by hand-plotting U.S. tornadoes classified as weak, strong, and violent tornadoes.



Since completing this map, the University of Chicago Tornado Tape (1916-1985) was completed, allowing us to produce grid-print maps which are presented in this book.

1.3 Characteristics of Subboxes

For the purpose of mapping tornadoes by computer, the contiguous United States is divided into subboxes bounded by 15'x 15' of latitude and longitude. In other words, each of the 1° x 1° squares of latitude and longitude is divided into 16 subboxes. Of these, 13,689 subboxes, including at least 10% land area, were chosen to be the statistical subboxes.

Each of the 13,689 subboxes is characterized by the six parameters in Table 1.1. WATER INDEX corresponds to the fractional water area; FOREST INDEX, to the fractional forest area; TOPOGRAPHY INDEX, to the mean slope inside a one-square-mile area averaged over the entire subbox; ROAD INDEX is related to the average separation of roads within a subbox; COMMUNITY INDEX, to the number of communities with a population of 500 or greater; and POPULATION INDEX signifies the total population within the subbox. For the distributions of these indices, refer to Figs. 1.3, 1.4, 1.5, 1.6, 1.7, and 1.8.

Table 1.1 Six indices which characterize the 15'x 15' subboxes in the contiguous United States. The upper line shows the index, 1 through 9, and the lower line, the description of each index.

Water Index	(WI)	1	2	3	4	5	6	7	8	9
Water Area	(W)	0/9	1/9	2/9	3/9	4/9	5/9	6/9	7/9	8/9 or larger
Forest Index	(FI)	1	2	3	4	5	6	7	8	9
Forest Area	(F)	0/9	1/9	2/9	3/9	4/9	5/9	6/9	7/9	8/9 or larger
Topography Index	(TI)	1	2	3	4	5	6	7	8	9
Slope Within mi^2	(T)	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6 X 1000' or larger
Road Index	(RI)	1	2	3	4	5	6	7	8	9
Road Separation	(R)	1	2	3	4	5	6	7	8	9 miles or larger
Community Index	(CI)	1	2	3	4	5	6	7	8	9
Community	(C)	0	1	2	4	7	11	16	22	28 or more
Population Index	(PI)	1	2	3	4	5	6	7	8	9
Population	(P)	0.0	0.1	0.8	2.7	6.4	12.5	21.6	34.3	51.9 X 1000 or larger

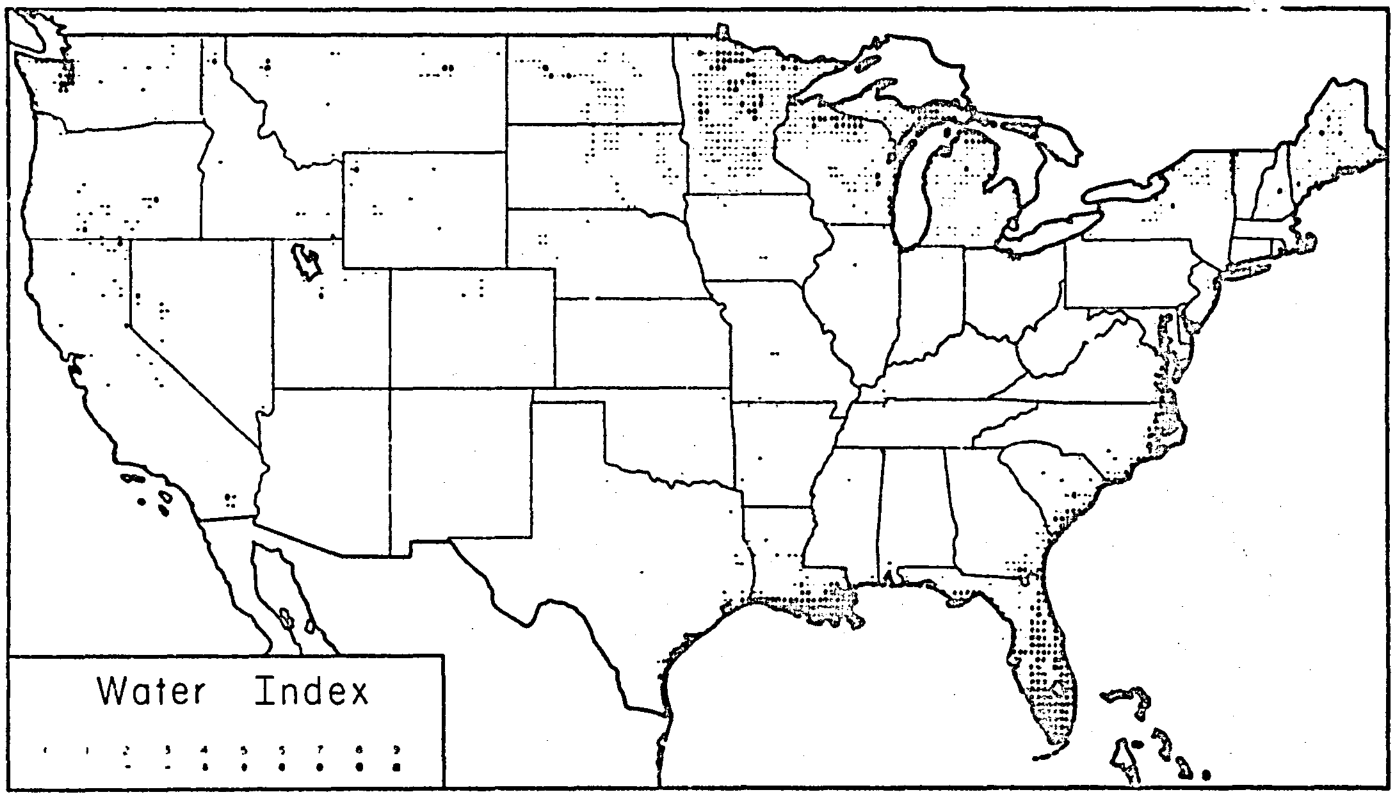


Fig. 1.3 Distribution of the water index, representing the fractional water area within each subbox. Large water areas are seen in the swamp regions in the Florida peninsula and in the Mississippi Delta. Subboxes with no water areas are not colored.

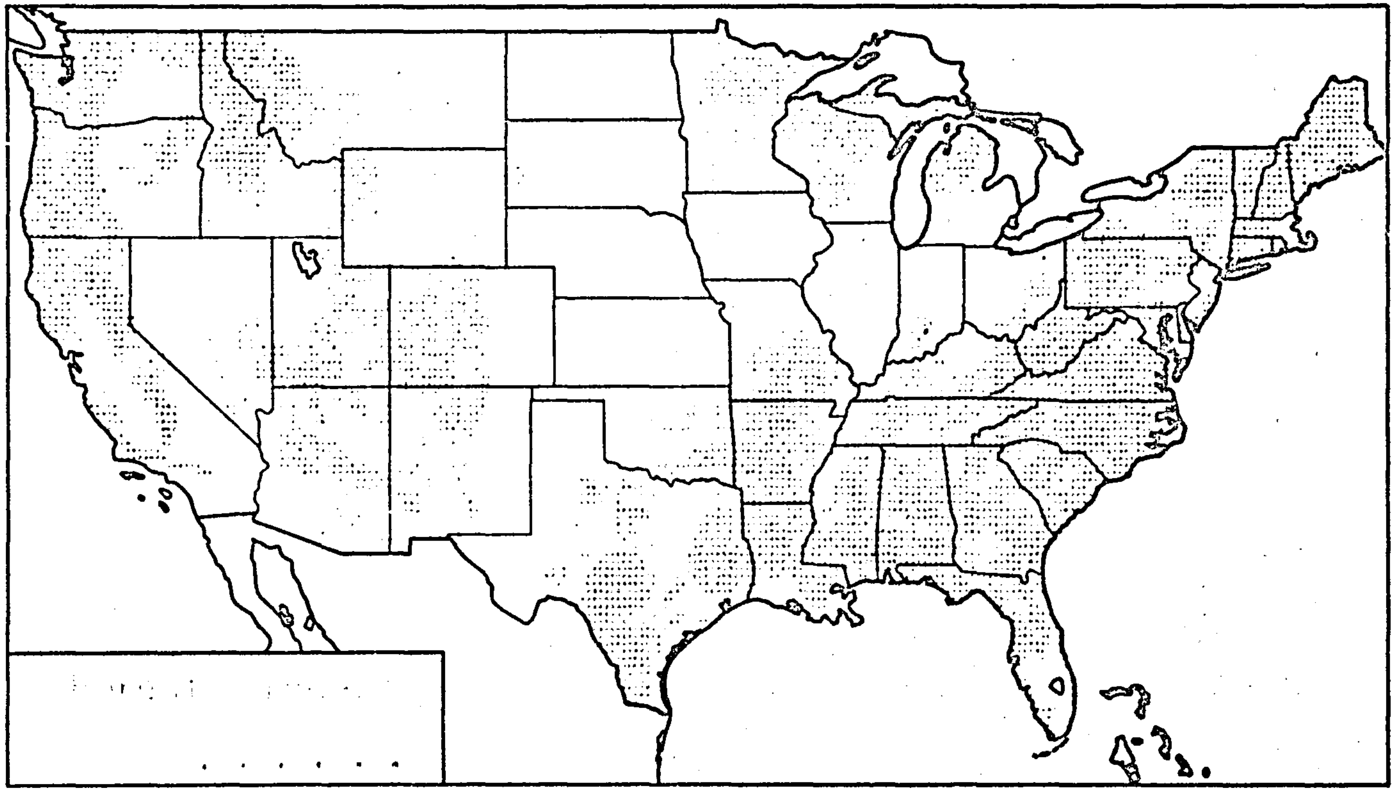


Fig. 1.4 Distribution of forests revealed by the forest index, which represents the fractional area of forests within each subbox. Tornadoes are more likely to be spotted in open areas than in forested areas which are shown with dark squares.

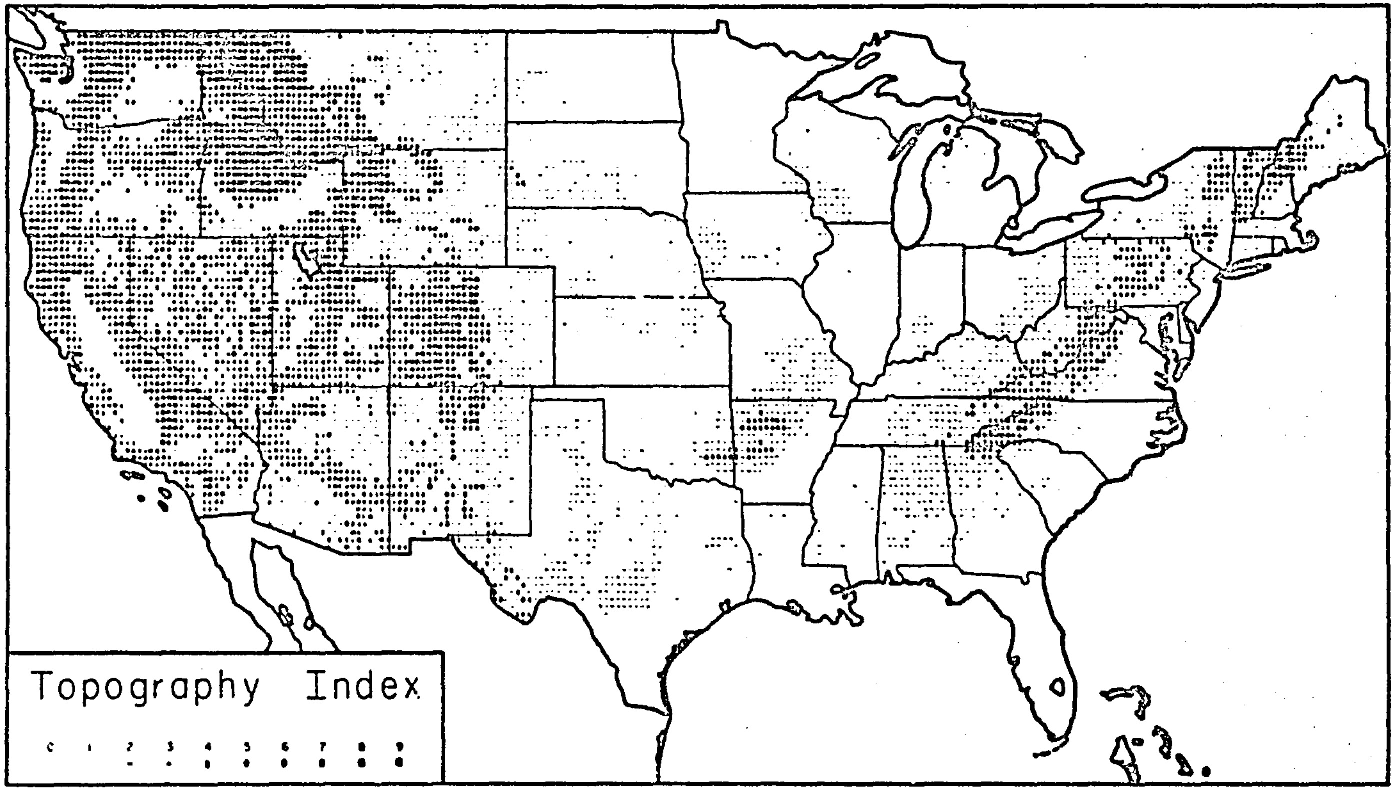


Fig. 1.5 Distribution of the topography index related to the mean slope, not altitude, of the land surface within each subbox. Relatively flat spots in the Rockies appear to be white spots on this map.

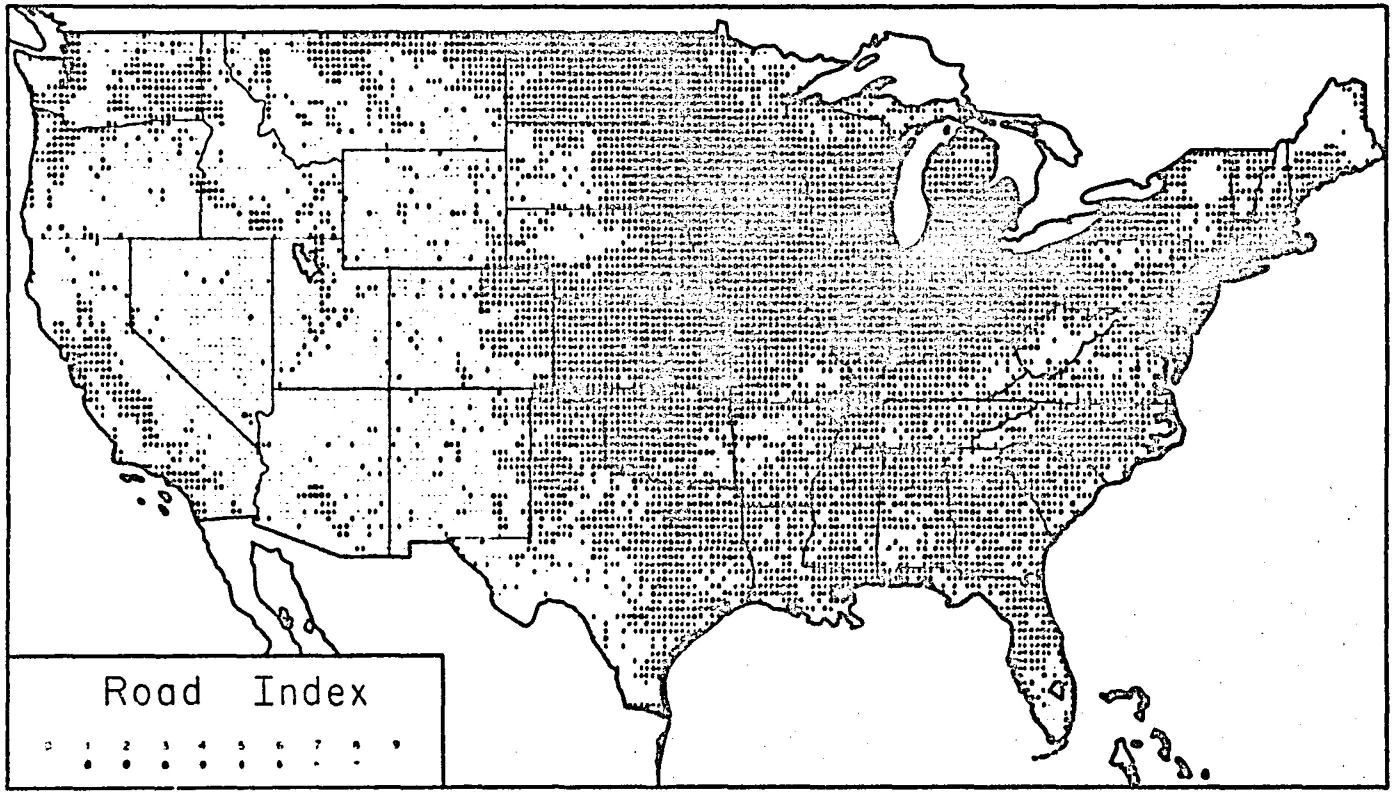


Fig. 1.6 Distribution of the road index which expresses the density of roads to be used for the purpose of tornado confirmations. Dark subboxes denote those of dense road networks.

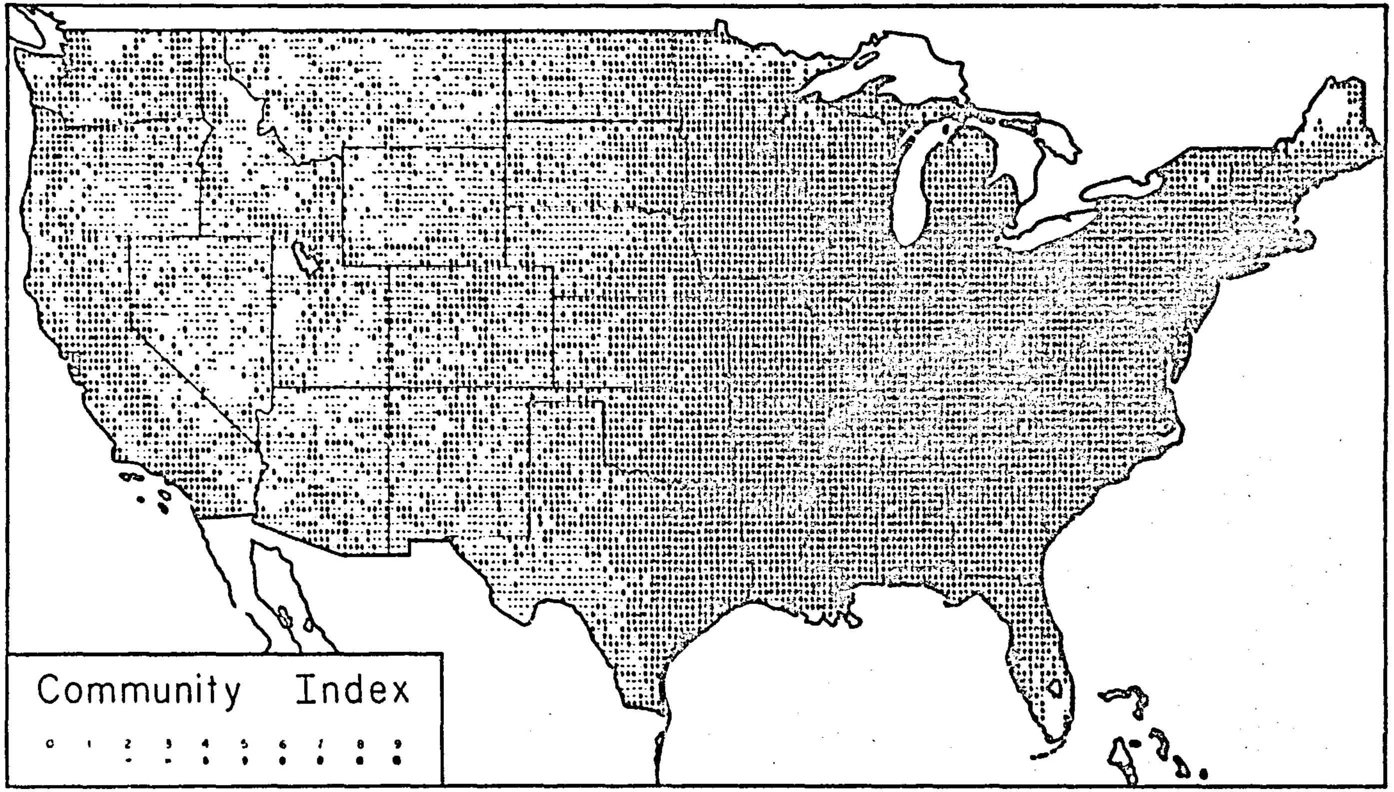


Fig. 1.7 Distribution of the community index which is the measure of the number of communities with a population of 500 or greater. Dark subboxes denote high-density communities.

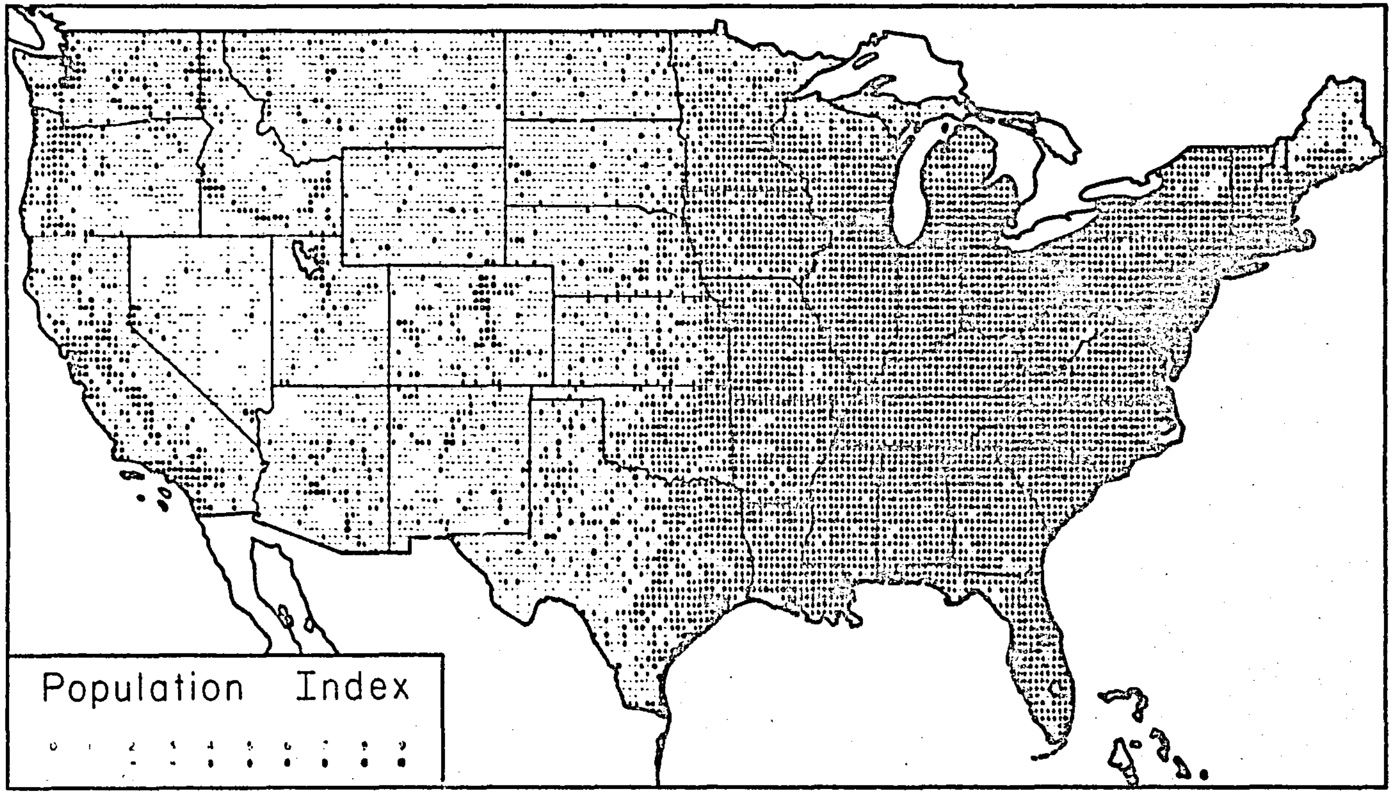


Fig. 1.8 Distribution of the population index. Blank areas denote population of less than 100 within a subbox. The completely colored subbox is characterized by a population of 51,200 or greater.

Chapter Two

University of Chicago Tornado Tape

Seventy years have passed since the official collection of U.S. tornado data began on January 1, 1916. During this 70-year period (1916-1985), a total of 31,054 tornadoes were confirmed in the contiguous United States. Tornado occurrences, defined as the number of confirmed tornadoes within a specific time and/or area, vary significantly from year to year due to annual variation of tornado activities, public awareness, and the official effort of archiving.

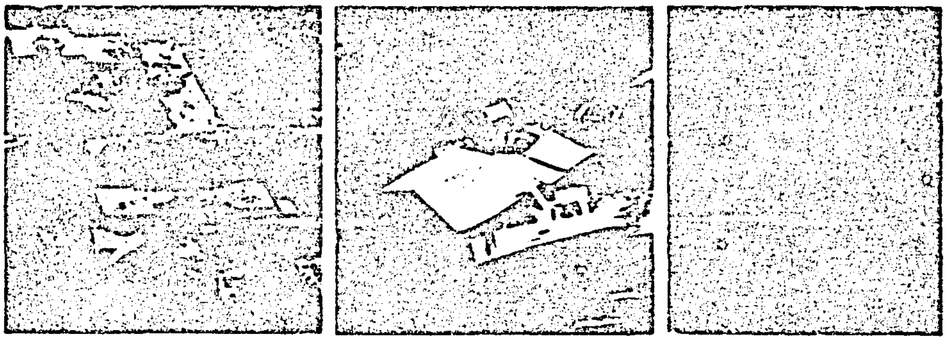
The basic statistical problem of the tornado is that not all tornadoes are alike. Some are violent, while others are weak. Long-lived tornadoes could travel across the Great Plains through hundreds of miles before they disappear. Quite often, we experience small tornadoes which leave behind narrow paths of destruction. In archiving this data in the University of Chicago Tornado Tape, an attempt was made to differentiate; weak tornadoes from strong ones; short-lived tornadoes from long-lived ones; and small tornadoes from the giant-sized ones.

2.1 The Fujita Tornado Scale (F scale)

The Fujita tornado scale (F scale) devised by Fujita (1971) was used to classify U.S. tornadoes in six intensity categories, F0-F5. Figure 2.1 presents photographs and descriptions of the six-point scale.

Photographs and Description of

[F0] LIGHT DAMAGE (40 - 72 mph) Some damage to chimneys; break twigs and branches off trees; push over shallow-rooted trees; damage signboards; some windows broken; hurricane wind speed begins at 73 mph.

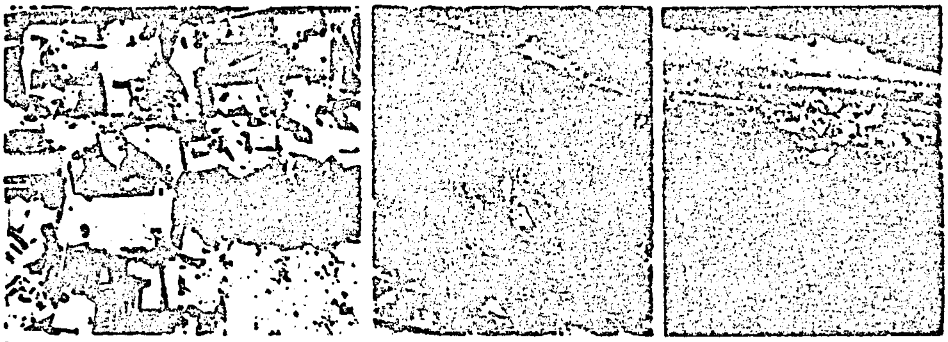


[F1] MODERATE DAMAGE (73 - 112 mph) Peel surface off roofs; mobile homes pushed off foundations or overturned; outbuildings demolished; moving autos pushed off the roads; trees snapped or broken.

[F2] CONSIDERABLE DAMAGE (113 - 157 mph) Roofs torn off frame houses; mobile homes demolished; frame houses with weak foundations lifted and moved; large trees snapped or uprooted; light-object missiles generated.

Fig. 2.1 The Fujita tornado scale. F0 to F2 are on the left page, while F3 to F5 are on the right page.

Fujita Tornado Scale (F0 - F5)



[F3] SEVERE DAMAGE (158 - 206 mph) Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown; weak pavement blown off the roads.

[F4] DEVASTATING DAMAGE (207 - 260 mph) Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and disintegrated; trees in forest uprooted and carried some distance away.

[F5] INCREDIBLE DAMAGE (261 - 318 mph) Strong frame houses lifted off foundations and carried considerable distance to disintegrate; automobile-sized missiles fly through the air in excess of 300 ft; trees debarked; incredible phenomena will occur.

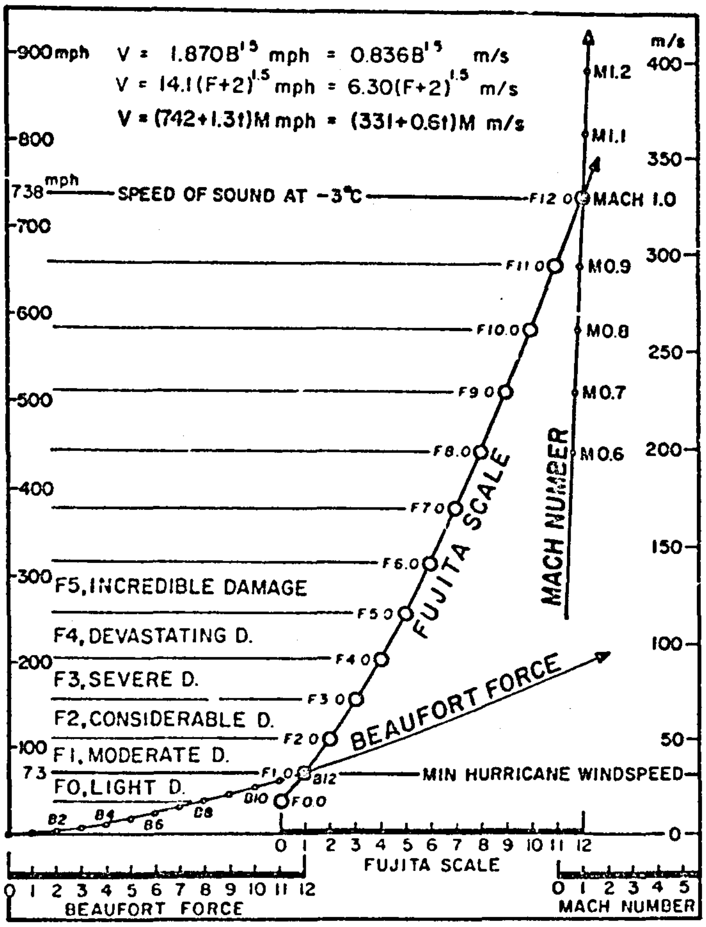


Fig. 2.2 Windspeeds of the Fujita tornado scale, which was obtained by connecting Beaufort Force 12 with Mach 1 in 12 steps. The windspeed of B12 or F1 is the minimum windspeed required to upgrade a tropical storm into a hurricane. The maximum windspeeds in U.S. tornadoes are estimated to be F5 (261 to 318 mph).

2.2 The University of Chicago Tornado Tape

Through tedious mapping of the path of each tornado, the following parameters in each subbox were obtained for entry into the tornado tape.

Tornado identification number
Year, Month, Day, and Time (CST)
Death and injuries by each tornado
Tornado F-scale, path length, and path width
Direction of movement

All historical tornadoes since 1916 have been included in the tape.

The source of the data in assessing and mapping the 70-year tornadoes are:

1916-34	Report of the Chief of the Weather Bureau
1935-49	Monthly Weather Review
1950-58	Climatological Data
1959-	Storm Data which includes the F-scale of every tornado since July 1981.

When ground and/or aerial surveys were available from the National Weather Service Offices, storm research agencies, newspapers, and the University of Chicago survey team, their results were used as supplemental data.

2.3 Occurrences and Path Lengths by F scale

During the 70-year period, 1916-1985, the 31,054 tornadoes in the contiguous United States left behind a cumulative path length of 132,005 miles, the equivalent of circling the world along the equator over five times. Tables 2.1 and 2.2 present both occurrences and path lengths in each decade. Due to the beginning and ending years of the tornado data used in these tables, the 1910 decade includes only four years and the 1980 decade, six years ending on December 31, 1985.

Total occurrences and path lengths are also presented in Fig. 2.3 in graphical forms. It is shown that F1 tornadoes are the most numerous in occurrence (37.3%), while the F2 tornadoes dominate the cumulative path length (32.5%). The reason for this shift in F scale is due to the fact that the higher the F scale, the longer the mean path length. As shown in Table 2.3, a significant increase in the mean path length corresponds to an increase in the F scale. In other words, the mean path length of the F0 tornadoes is only 1.2 miles, while that of the F5 tornadoes reaches 35.5 miles.

Table 2.1 Occurrences of tornadoes during the 70-year period.

Year	F 0	F 1	F 2	F 3	F 4	F 5	ALL	
1916-19	32	101	150	67	32	10	392	tornadoes
1920-29	73	336	578	311	73	20	1,391	
1930-39	274	447	717	276	69	9	1,792	
1940-49	174	322	682	355	103	13	1,649	
1950-59	1,038	1,945	1,346	470	112	8	4,919	
1960-69	1,951	2,615	1,769	584	103	9	7,031	
1970-79	2,396	3,653	1,910	570	107	16	8,652	
1980-85	1,973	2,155	811	245	41	3	5,228	
TOTAL	7,911	11,574	7,963	2,878	640	88	31,054	tornadoes
	25.5	37.3	25.6	9.3	2.0	0.3	100	in %

Table 2.2 Path lengths of tornadoes during the 70-year period. It should be noted that individual path lengths are coded in the tape to the nearest .5 mile. Individual entries in this and ensuing path length tables are independently computed and each is rounded up to the nearest mile. Hence, totals may not add up exact.

Year	F 0	F 1	F 2	F 3	F 4	F 5	ALL	
1916-19	143	431	1,504	1,061	1,238	464	4,840	miles
1920-29	167	1,101	5,034	3,330	2,320	1,148	13,098	
1930-39	952	1,880	4,618	2,709	1,664	75	11,897	
1940-49	415	1,423	4,956	3,849	3,264	355	14,261	
1950-59	1,706	6,739	8,306	4,983	2,404	188	24,324	
1960-69	2,103	6,065	6,838	4,591	2,667	341	22,604	
1970-79	2,396	8,305	7,766	5,692	2,827	416	27,401	
1980-85	1,701	4,288	3,819	2,594	1,042	138	13,581	
TOTAL	9,582	30,230	42,838	28,807	17,424	3,124	132,005	miles
	7.3	22.9	32.5	21.8	13.2	2.4	100	in %

Table 2.3 Mean path lengths of tornadoes by F scale.

	F 0	F 1	F 2	F 3	F 4	F 5
Total path length	9,582	30,230	42,838	28,807	17,424	3,124 miles
Total occurrence	7,911	11,574	7,963	2,878	640	88 tornadoes
Mean path length	1.2	2.6	5.4	10.0	27.2	35.5 miles

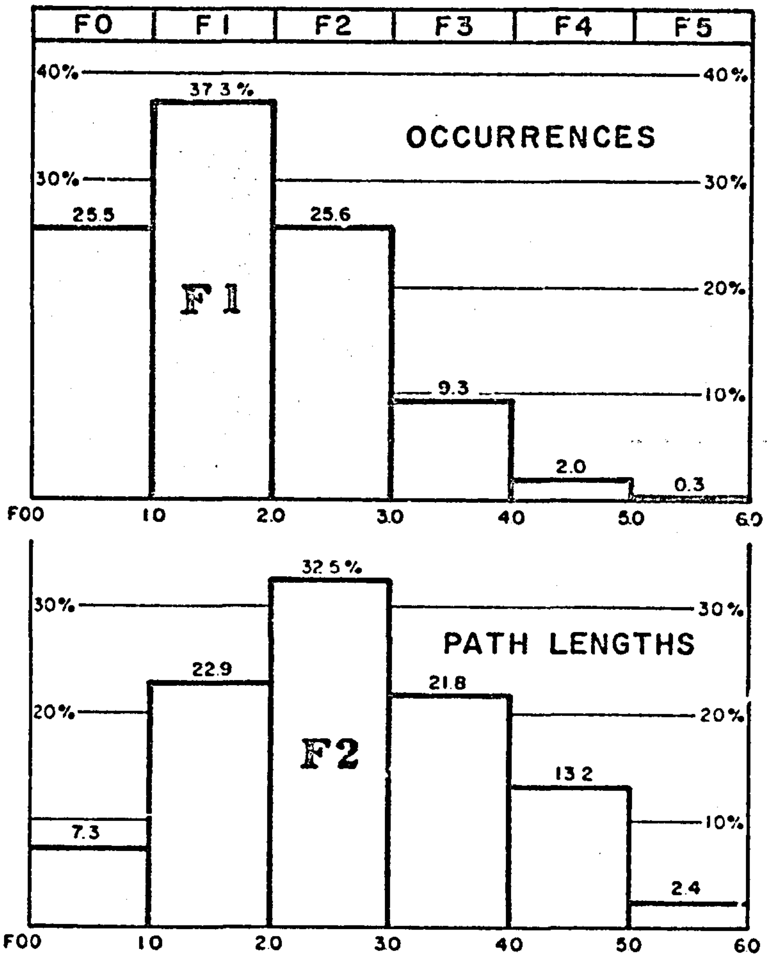


Fig. 2.3 Tornado occurrences by F scale (upper diagram) and path lengths by F scale (lower diagram). All available data during the 70-year period, 1916-1985, were used. For numerical values, refer to Tables 2.1 and 2.2.

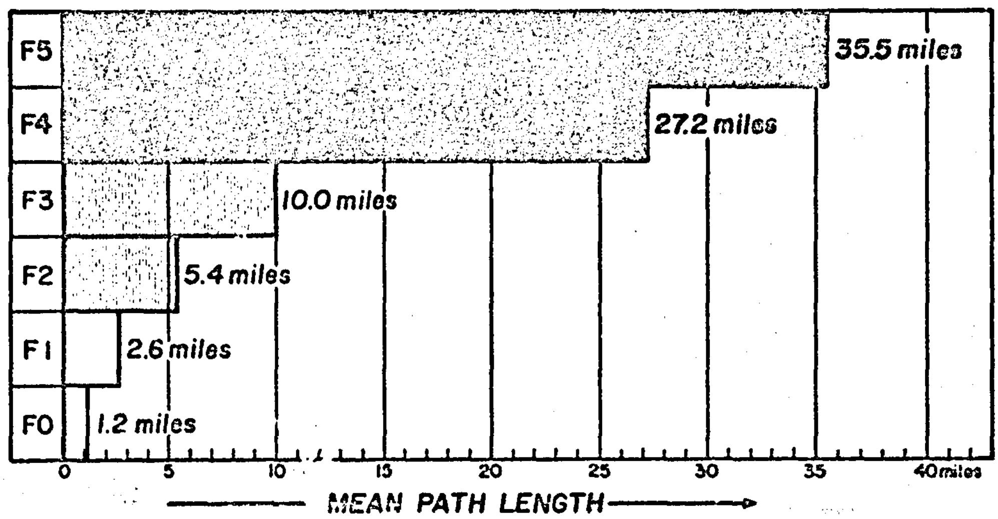


Fig. 2.4 Mean path length of tornadoes by F scale. This diagram shows that the path length increases significantly with the F scale. The smaller fractional increase between F4 and F5 tornadoes suggests that most tornadoes classified as F5 are in the lower F5 range.

2.4 Geographic Distribution by F scale

An attempt was made to depict geographic distributions of tornadoes by their occurrences and path lengths. For this purpose, the segments of the paths included inside each subbox were measured and added by computer to determine the total path length of tornadoes within a subbox.

Occurrences of tornadoes in each subbox were computed by adding the number of initial touchdowns. However, if a tornado touches down inside a subbox and moves out into an adjacent subbox, no occurrence count is made for the adjacent subbox, only the subbox of the initial touchdown. In this mapping procedure, the total occurrences are identical to the number of confirmed tornadoes which begin at an initial touchdown point and end at a final liftoff point.

Presented in Figs. 2.5 and 2.6 are the occurrence and path-length patterns of all tornadoes (F0 through F5) during the 70-year period. These figures reveal that tornadoes occur predominantly over the Midwestern plains. Their distributions are, however, affected by local forests, topography, and population which are shown in grid-print map form in Figs. 1.3 through 1.8.

The distribution of weak tornadoes (F0+F1) are depicted in Figs. 2.7 and 2.8. Likewise, those of strong tornadoes (F2+F3) are shown in Figs. 2.9 and 2.10. Finally, the patterns of violent tornadoes (F4+F5) are depicted in Figs. 2.11 and 2.12.

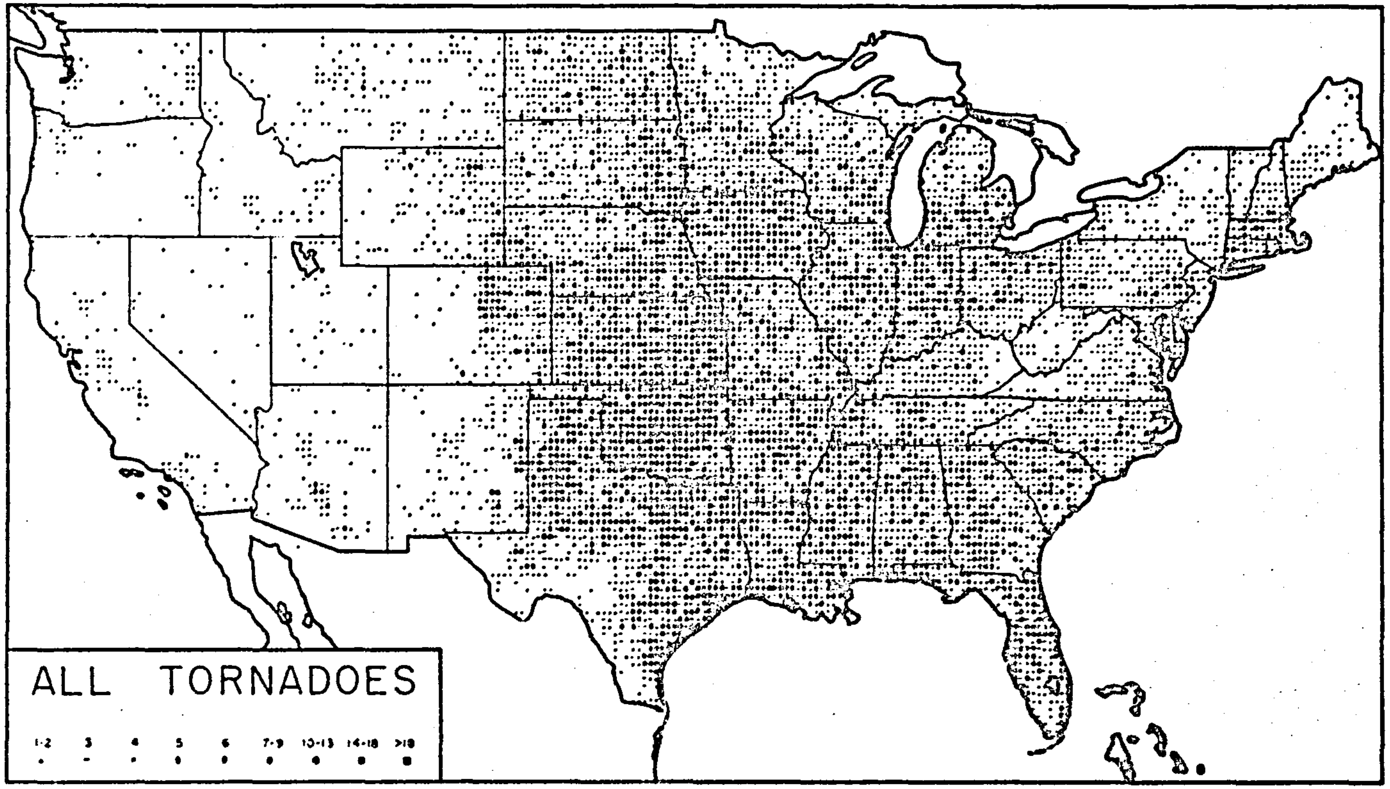


Fig. 2.5 Occurrences of F0 through F5 tornadoes during the 70-year period, 1916-1985. The areas of high-density occurrences extend from northern Texas to Iowa. High occurrences along the Gulf Coast are primarily due to hurricane-spawned tornadoes.

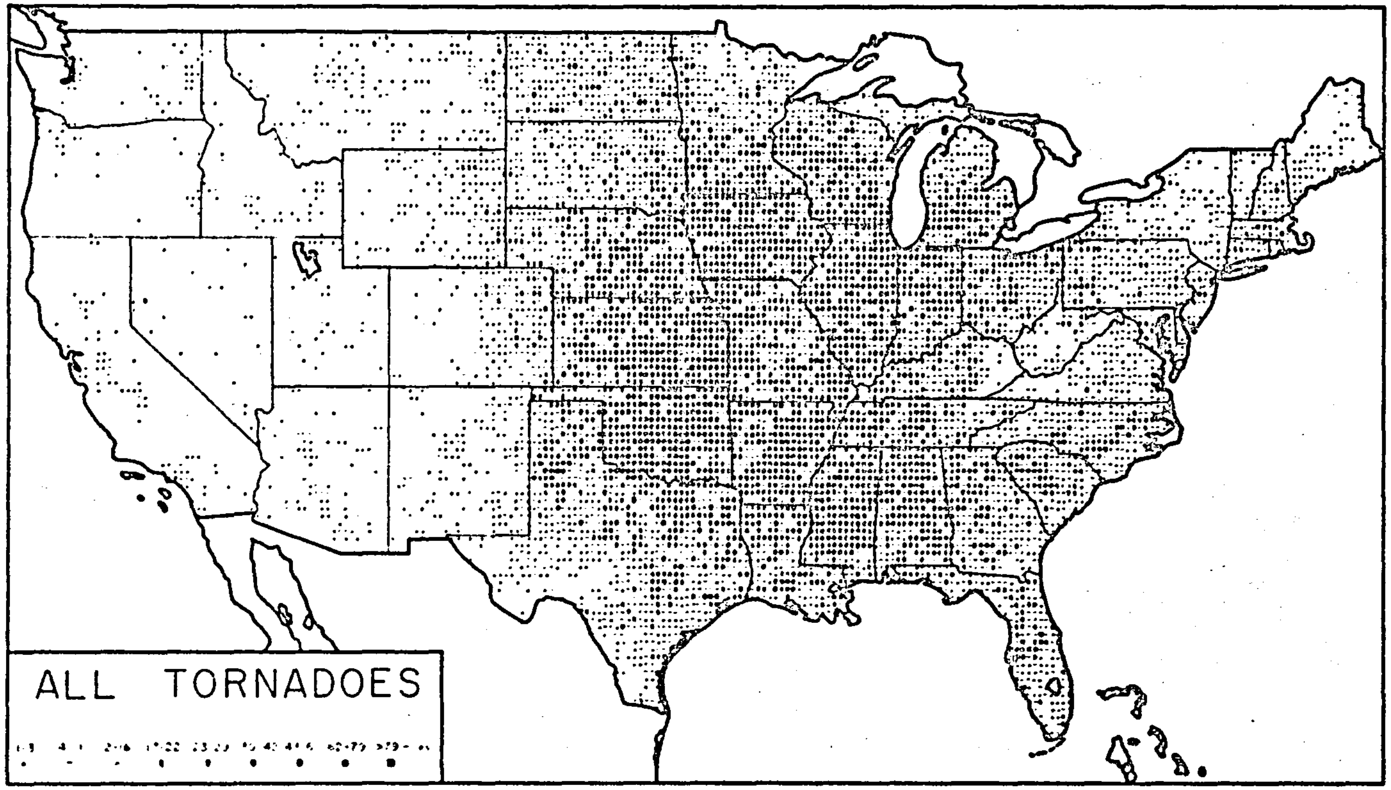


Fig. 2.6 Path lengths of F0 through F5 tornadoes during the 70-year period, 1916-1985. Unlike tornado occurrences, the regions of large path lengths cover 13 states centered around Missouri. In particular, Illinois, Arkansas, and Mississippi are very high in path-length density.

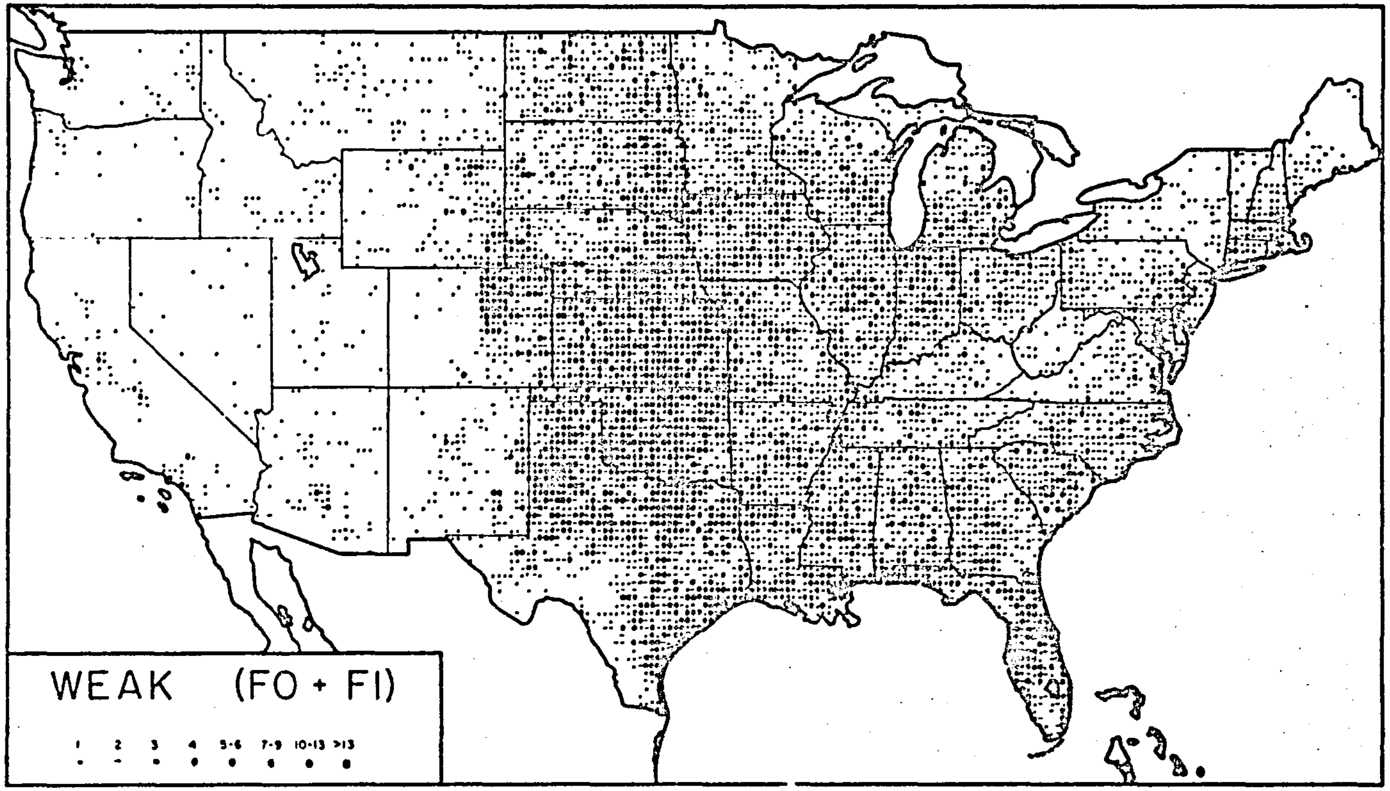


Fig. 2.7 Distribution of the occurrence of weak tornadoes (F0+F1) during the 70-year period, 1916-1985. Hurricane-spawned tornadoes dominate the Gulf coast of Texas through Florida. An area of concentrated occurrences extends northward from Oklahoma to Nebraska.

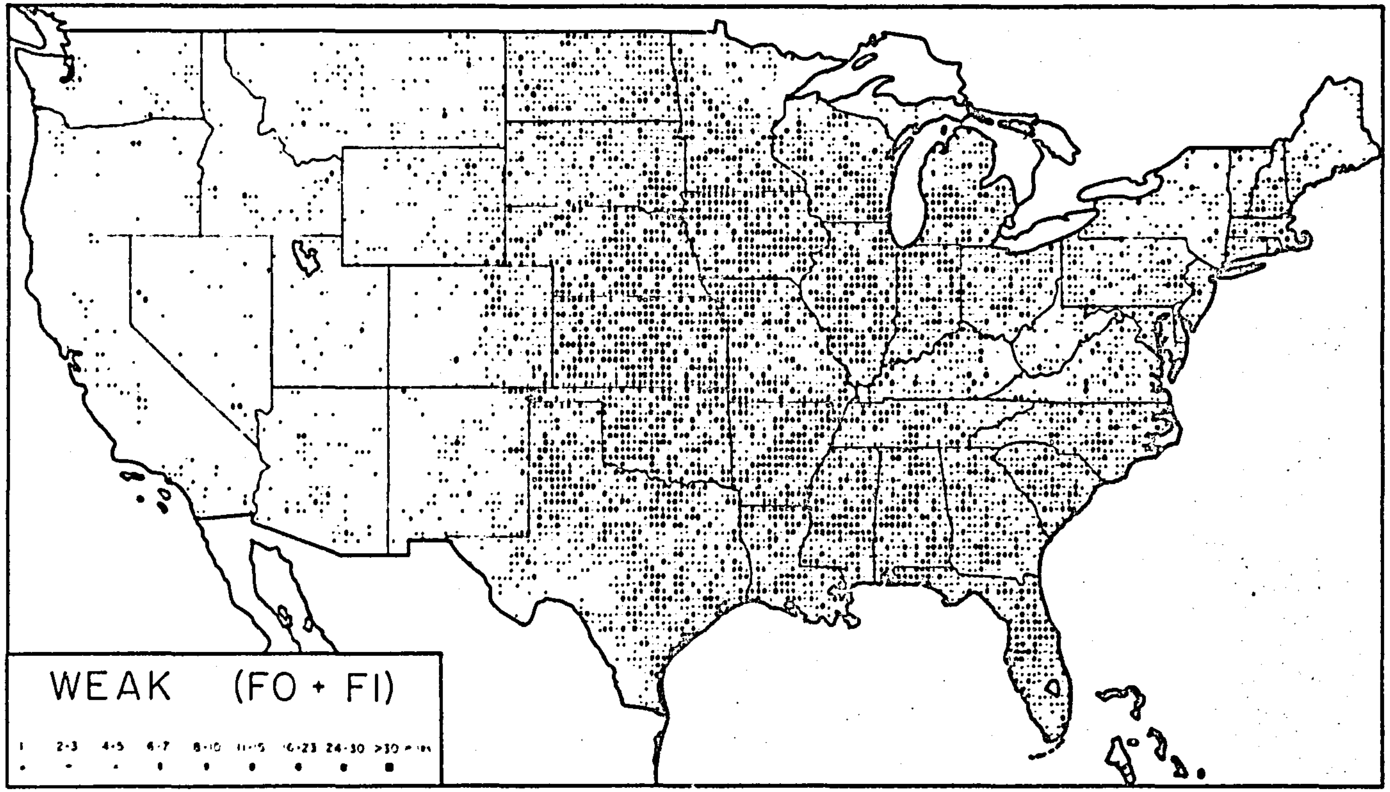


Fig. 2.8 Distribution of the path length of weak tornadoes (F0+F1) during the 70-year period, 1916-1985. The area of high-density path lengths extends through Oklahoma, Kansas, Iowa, Illinois, and Arkansas.

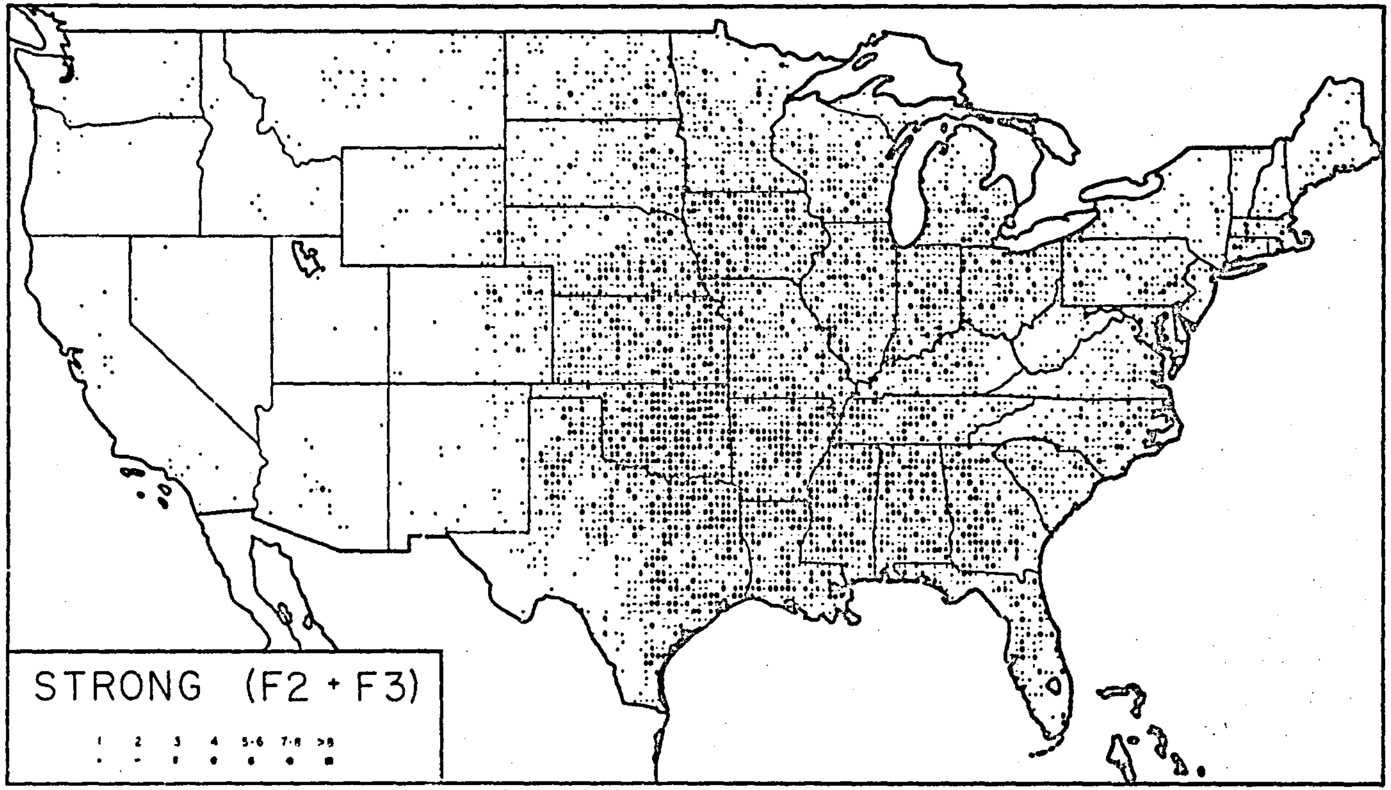


Fig. 2.9 Distribution of the occurrence of strong tornadoes (F2+F3) during the 70-year period, 1916-1985. The center of the high-density occurrences is in Oklahoma.

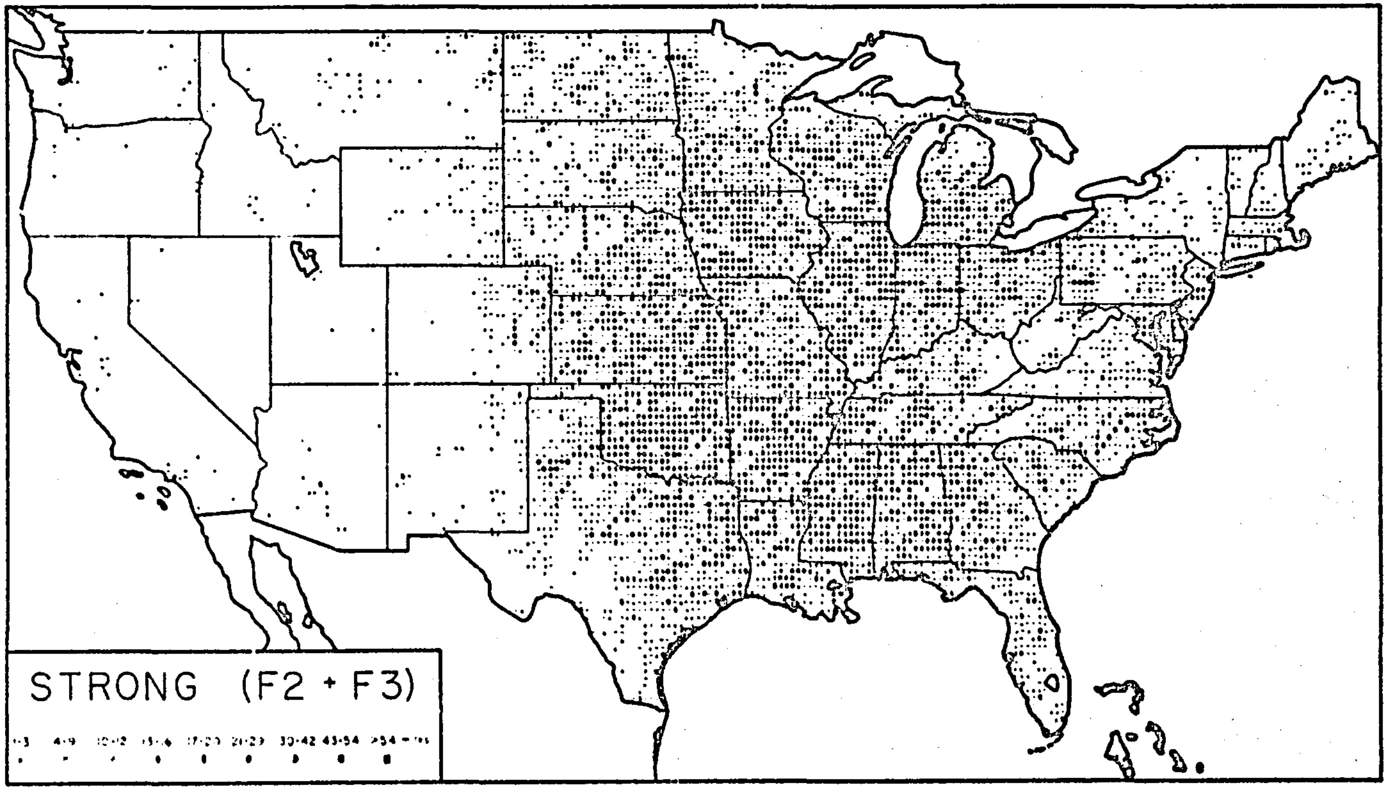


Fig. 2.10 Distribution of the path length of strong tornadoes (F2+F3) during the 70-year period, 1916-1985. The area of high-density path length is rather diffused, covering a vast area of the Midwest.

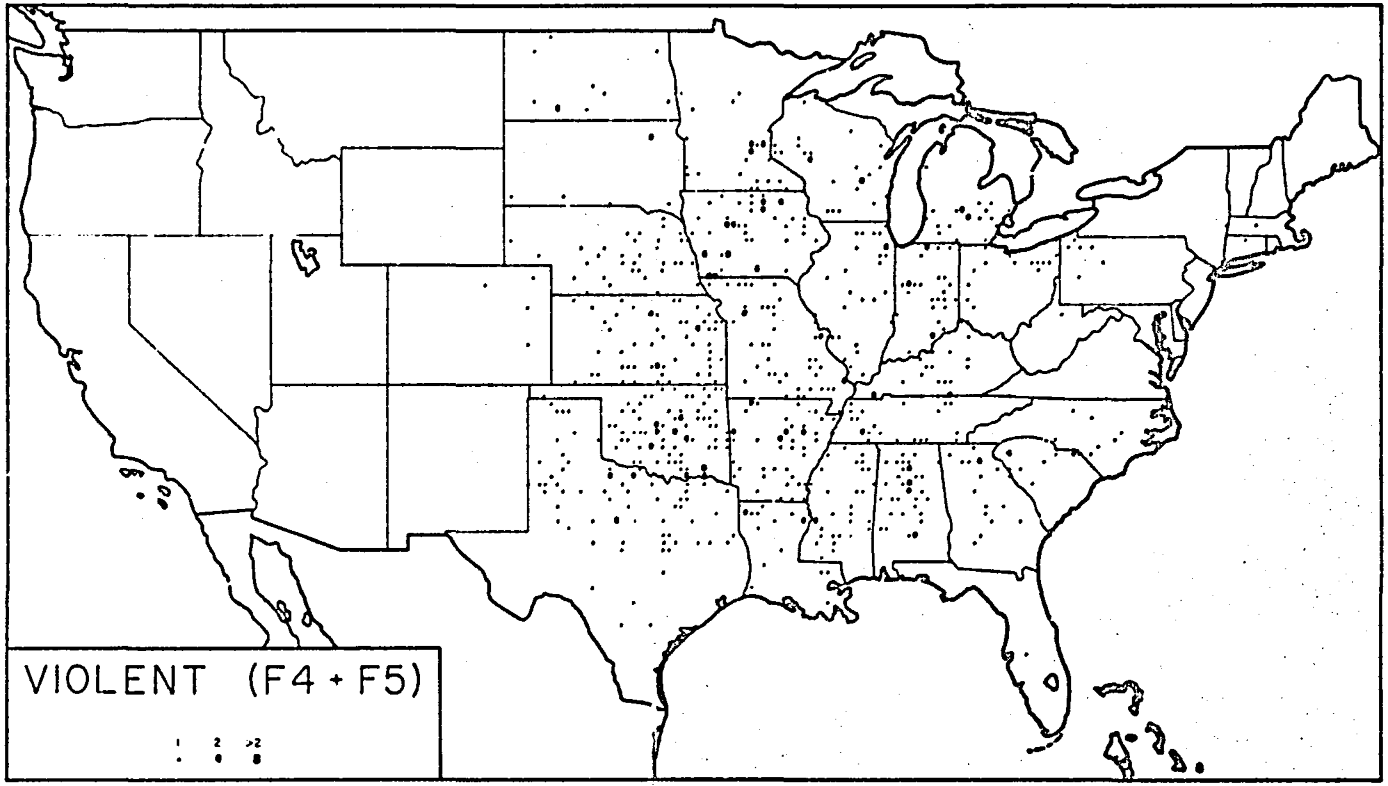


Fig. 2.11 Distribution of the occurrence of violent tornadoes (F4+F5) during the 70-year period, 1916-1985. Due to the relatively small number of violent tornadoes, the pattern is rather erratic.

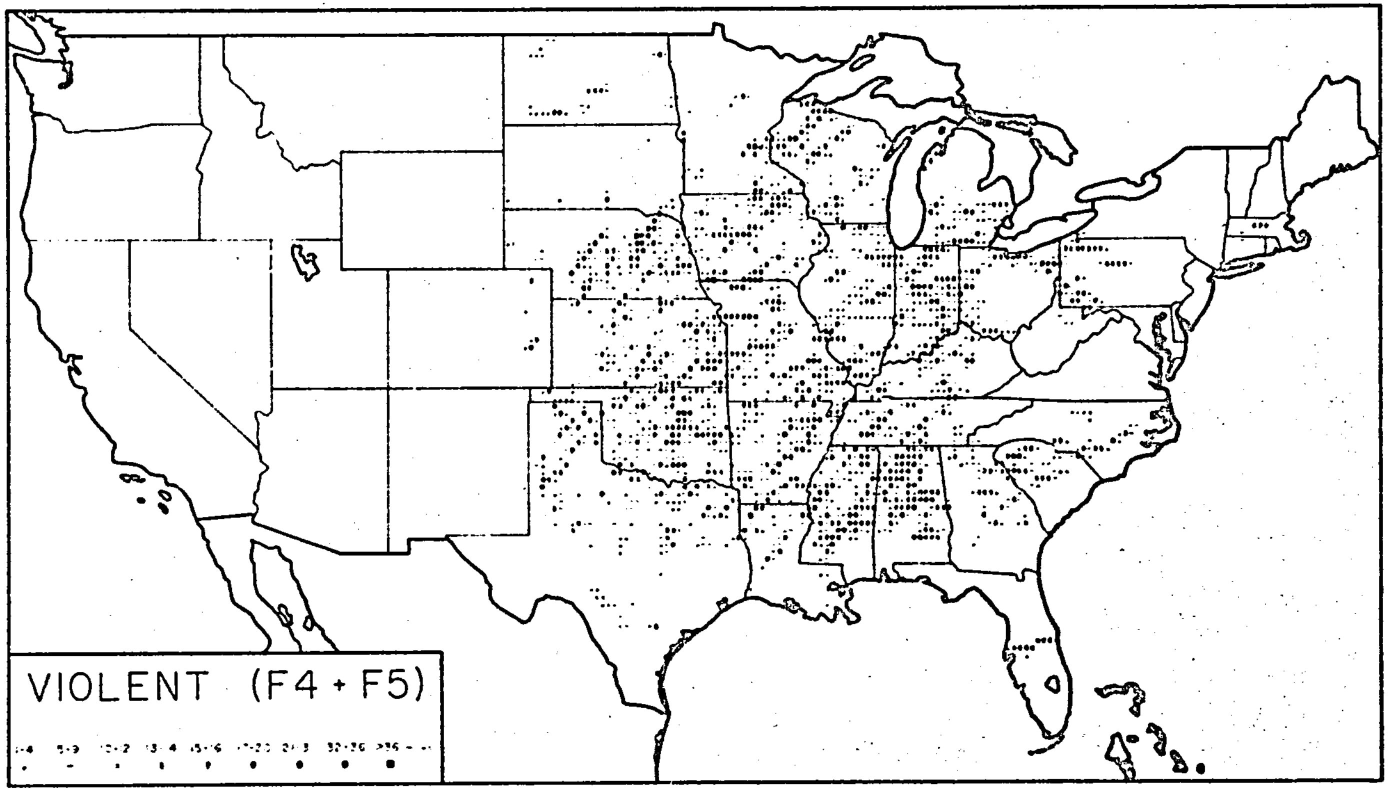


Fig. 2.12 Distribution of the path length of violent (F4+F5) tornadoes during the 70-year period, 1916-1985. Because of the long path lengths of violent tornadoes, the path-length pattern depicts the damage swaths left behind by these tornadoes.

The so-called tornado capitals of the United States can be identified in Figs. 2.5 through 2.12. First of all, we will have to specify "occurrence" or "path length", as well as "weak", "strong", or "violent" tornadoes.

The capital of "weak tornado occurrence" is Oklahoma and Kansas (See Fig. 2.7). Whereas, that of "weak tornado path length" is not unique, so that we have to choose a vast area in which several capitals are to be found.

Most importantly, path lengths of violent (F4+F5) tornadoes are found almost uniformly inside the area bounded by Duluth, MN; Pittsburgh, PA; Norfolk, VA; Tallahassee, FL; Austin, TX; Tucumcari, NM; Denver, CO; and back to Duluth, MN.

Chapter Three

Long-term Variation

The long-term variation of tornadoes expressed by annual occurrences is influenced by (1) the true variation of tornado activities, and (2) the collection efficiency of tornado data. Because these natural and man-made variations are intermixed, it is difficult to assess the true variation of tornado activities based on historical data alone.

3.1 Tornado Occurrences in 70 Years

An attempt was made to present tornado occurrences as functions of the year and the F scale. A three-dimensional diagram in Fig. 3.1 was constructed by dividing the 70-year statistical period into seven 10-year subperiods, 1916-25, 1926-35, 1936-45, 1946-55, 1956-65, 1966-75, and 1976-85.

This diagram reveals that the occurrences of violent tornadoes (F4+F5) were rather uniform throughout the 70-year period. Whereas, strong tornadoes (F2+F3) kept increasing steadily with the exception of a decrease during the recent 10-year subperiod. A significant increase in tornado occurrence since the 1950s is attributed to the improved efficiency in reporting and confirming weak tornadoes (F0+F1).

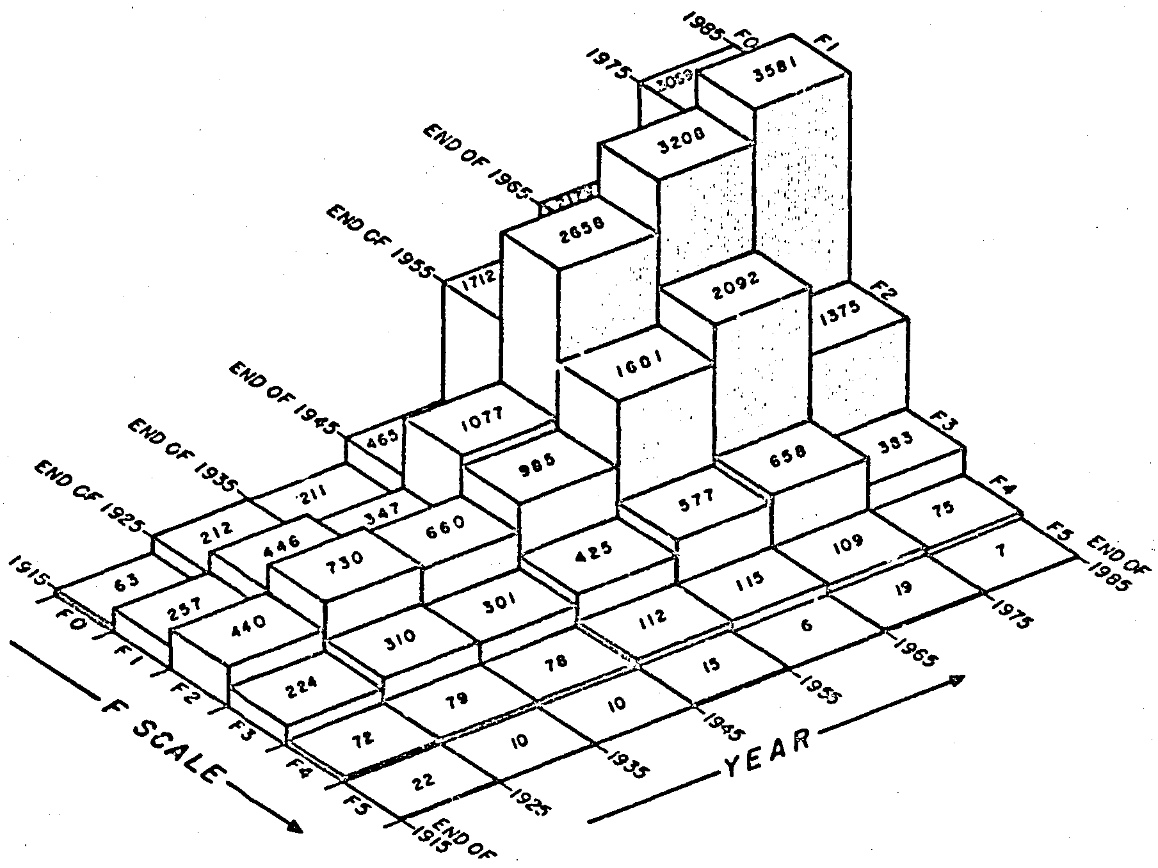


Fig. 3.1 A three-dimensional diagram showing the tornado occurrences by F scale during the 10-year subperiods between 1916 and 1985. Note that occurrences of violent tornadoes (F4+F5) remain unchanged, while strong tornadoes (F2+F3) kept increasing gradually. Improved reporting of weak tornadoes (F0+F1) resulted in a significant increase in the occurrences of U.S. tornadoes since the 1950s.

3.2 Annual Occurrences

A bar graph of the annual occurrences of tornadoes in Fig. 3.2 reveals that less than 300 tornadoes were confirmed until the end of 1952, when a sudden increase took place, confirming 886 tornadoes in the year 1957. After reaching the record number of 1,110 in 1973, annual occurrences indicate a slight decrease. In spite of the fact that tornado occurrences fluctuated between 68 and 1,110, a factor of 16, there is no reason to believe the existence of such a large variation in tornado activities during the 70-year period. Most of the increase was a result of the reporting efficiency and confirmation skill of F0 and F1 tornadoes which were overlooked during the early data-collection years.

Because it is likely that long-path tornadoes are reported more efficiently than short-path storms, annual path lengths are a better measure of tornado activities than annual occurrences. Shown in Fig. 3.3 is a bar diagram of the annual path lengths during the 70-year period. Although the path lengths vary between 507 and 4,996, a factor of 10, their long-term increase appears to be less significant than that of occurrences presented in Fig. 3.2.

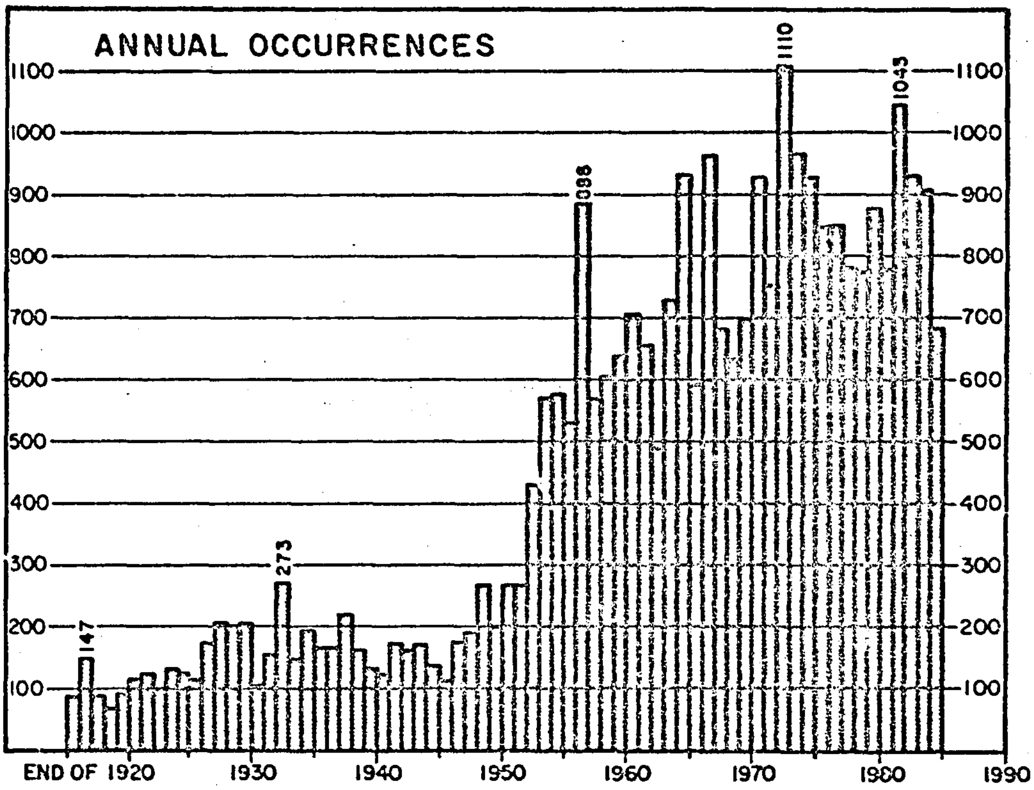


Fig. 3.2 Annual occurrences of U.S. tornadoes during the 70-year period ending on December 31, 1985. Statistical years shown at the bottom denote end of the years.

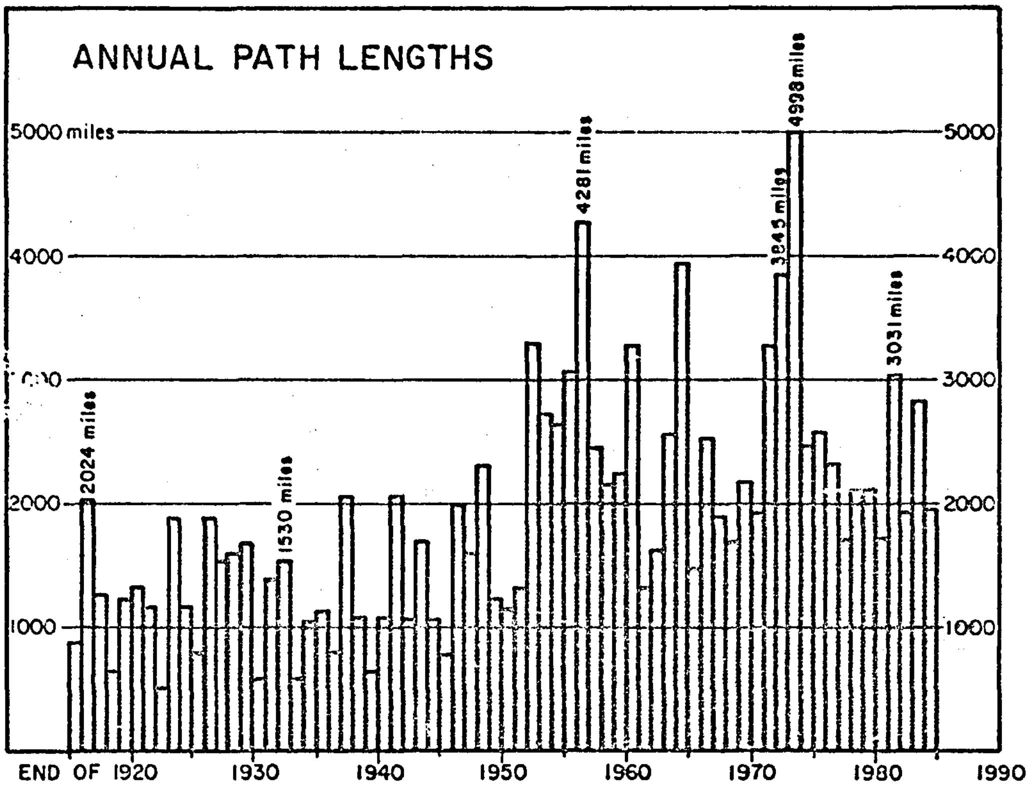


Fig. 3.3 Annual path lengths of U.S. tornadoes during the 70-year period ending on December 31, 1985. The long-term trend in the path-length increase is less significant than that of the occurrences. The longest annual path length of 4,998 miles occurred in the year 1974 when the "Superoutbreak Tornadoes", the worst outbreak in 70 years, left behind swaths of destruction in 13 states east of the Mississippi.

Table 3.1 Tornado occurrence and tornado path length recorded during the 70 years. 1916-85. Path lengths are rounded up to the nearest mile.

	OCCURRENCE							PATH LENGTH (Miles)						
Year	F0	F1	F2	F3	F4	F5	ALL	F0	F1	F2	F3	F4	F5	ALL
1916	16	28	29	8	6	0	87	112	179	195	140	270	0	895
1917	7	33	54	33	13	7	147	4	183	448	659	364	367	2024
1918	2	23	40	17	6	2	90	1	47	575	205	354	85	1267
1919	7	17	27	9	7	1	68	27	22	286	57	251	12	654
1920	8	20	33	16	9	7	93	4	23	210	343	279	370	1228
1921	5	31	51	22	3	3	115	7	42	694	302	88	191	1323
1922	7	27	57	26	5	0	122	52	84	607	239	191	0	1172
1923	4	28	32	31	5	0	100	8	36	194	168	102	0	[illegible]
1924	4	21	55	39	12	0	131	2	127	628	527	594	0	1878
1925	3	29	62	23	6	2	125	2	85	416	278	98	288	1166
1926	6	30	47	26	7	0	116	34	86	271	200	210	0	800
1927	10	33	80	38	10	5	176	14	122	783	524	227	209	1878
1928	12	61	82	46	8	0	209	32	296	581	408	231	0	1548
1929	14	56	79	44	8	3	204	16	202	651	343	302	90	1601
1930	19	42	95	33	15	1	205	49	357	65[illegible]	404	214	7	1681
1931	15	26	46	14	2	0	103	24	47	295	150	63	0	579
1932	34	41	57	12	12	0	156	172	102	371	158	578	0	1380
1933	50	62	107	41	12	1	273	120	298	498	484	131	1	1530
1934	26	33	64	23	3	0	149	62	49	305	115	66	0	596
1935	26	62	73	33	2	0	196	57	247	460	136	95	0	1053
1936	29	39	57	30	8	3	166	131	148	438	279	106	35	1134
1937	27	31	80	24	2	0	164	129	132	399	122	22	0	802
1938	23	65	80	39	9	3	219	146	354	797	490	234	0	2068
1939	25	46	58	27	4	1	161	65	168	409	314	96	25	1076
1940	17	27	60	20	5	0	129	37	173	233	111	94	0	647
1941	23	25	53	17	3	0	121	46	77	552	342	58	0	1075
1942	24	26	67	33	24	1	175	69	150	505	433	854	52	2062
1943	16	28	74	37	6	1	162	33	192	478	269	79	10	1061
1944	19	35	69	40	8	1	172	41	173	588	386	502	9	1698
1945	8	25	62	34	9	0	138	7	165	374	341	158	0	1044
1946	13	25	42	21	11	1	113	22	220	233	155	140	9	785
1947	13	34	76	38	10	4	177	41	89	494	783	415	169	1990
1948	10	33	80	55	11	3	192	7	76	756	436	287	48	1602
1949	31	64	97	60	16	2	270	115	115	740	294	678	59	2300
1950	20	84	66	25	7	0	202	44	403	391	225	172	0	1233
1951	47	127	69	22	5	0	270	175	456	333	152	49	0	1162
1952	27	86	92	47	18	0	270	127	178	350	372	290	0	1315
1953	69	149	140	52	18	4	432	92	649	1285	760	443	69	3298
1954	106	229	173	59	7	0	574	155	663	1039	671	182	0	2709
1955	129	246	148	46	9	1	579	219	1034	869	358	130	43	2652
1956	124	199	156	40	12	1	532	152	616	1292	529	417	61	3065
1957	221	318	237	84	24	2	886	300	1134	1320	981	532	16	4281
1958	156	251	113	44	5	0	569	204	833	704	643	70	0	2453
1959	139	256	152	51	7	0	605	241	775	725	296	123	0	2159
1960	117	294	163	58	7	0	639	108	842	583	529	165	0	2226
1961	163	260	195	83	6	0	707	269	728	1127	987	180	0	3290
1962	215	248	143	44	6	0	656	236	415	370	263	37	0	1319
1963	103	186	146	53	6	0	494	91	491	568	349	134	0	1632
1964	200	302	165	50	10	2	729	217	770	797	605	170	10	2567
1965	274	344	211	70	32	0	931	320	978	995	577	1083	0	3952
1966	181	216	150	39	4	3	593	125	391	397	195	160	223	1491
1967	302	324	242	78	16	1	963	306	601	916	420	260	29	2531
1968	192	238	183	56	9	3	681	152	537	557	347	224	80	1897
1969	204	203	171	53	7	0	638	282	314	529	321	256	0	1701
1970	174	239	218	59	7	2	699	166	462	718	596	210	25	2175
1971	194	389	255	81	9	2	930	203	825	972	777	476	29	3281
1972	170	346	181	52	4	0	753	137	794	556	347	82	0	1915
1973	219	501	289	87	13	1	1110	270	1234	1230	808	301	3	3845
1974	239	381	204	106	30	6	966	289	1117	1002	1409	905	278	4998
1975	304	371	199	47	10	1	932	309	902	767	340	143	18	2478
1976	244	359	176	54	13	3	849	223	708	728	547	316	50	2571
1977	255	378	168	41	9	1	852	238	887	545	489	179	14	2331
1978	330	324	105	18	5	0	782	329	692	559	99	28	0	1707
1979	267	365	115	25	7	0	779	235	686	671	323	189	0	2102
1980	270	428	152	34	5	0	879	227	870	659	275	78	0	2108
1981	301	322	129	25	4	0	781	294	654	541	187	38	0	1713
1982	375	433	172	58	6	1	1045	301	814	932	730	200	55	3031
1983	355	370	146	57	4	0	932	262	800	494	369	11	0	1936
1984	369	353	130	41	14	1	908	334	686	774	592	405	36	2826
1985	303	259	82	30	8	1	683	284	465	420	442	310	47	1968
TOTAL	7911	11574	7963	2878	640	88	31054	9582	30230	42838	28407	17424	3124	132005

3.3 Tornado Distribution by Decade

In an attempt to determine the long-term variation of tornado activities, grid-print maps of both occurrences and path lengths were produced by using the University of Chicago Tornado Tape containing the 70-year data. It is not feasible to produce tornado maps for each of the seven decades because the first year of data collection began in 1916.

Table 3.2 Decade and semi-decade maps produced for the period listed below.

Decades	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s
Periods	16-19	20-29	30-39	40-49	50-59	60-69	70-79	80-85
Years	3	10	10	10	10	10	10	6
Figs.	none	3.4 3.5	3.6 3.7	3.8 3.9	3.10 3.11	3.12 3.13	3.14 3.15	3.16 3.17

Each decade consists of an occurrence (upper charts) and a path-length (lower charts) map. In general, path-length maps depict composite movement of tornadoes, being enhanced by the activity of strong and violent tornadoes which are characterized by relatively long paths.

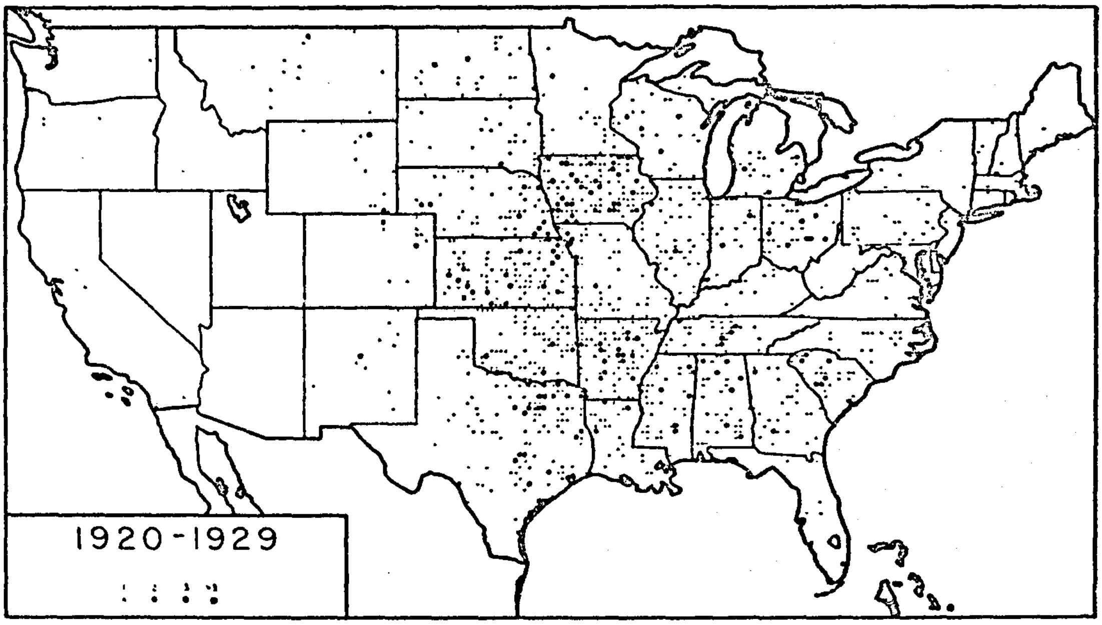


Fig. 3.4 Occurrences of tornadoes during the 1920s.

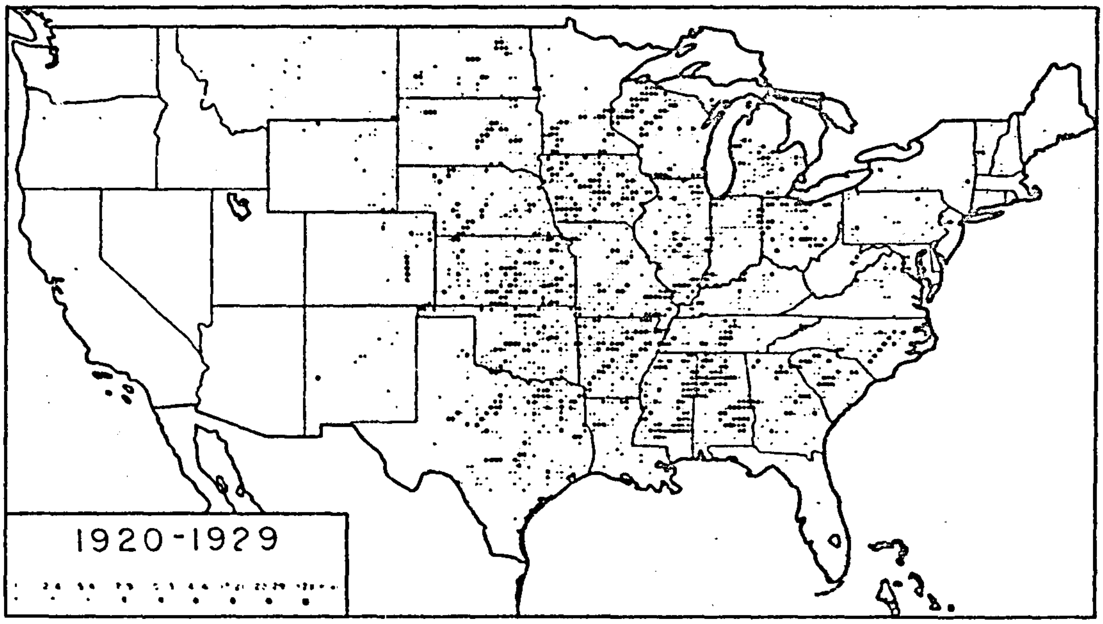


Fig. 3.5 Path lengths of tornadoes during the 1920s.

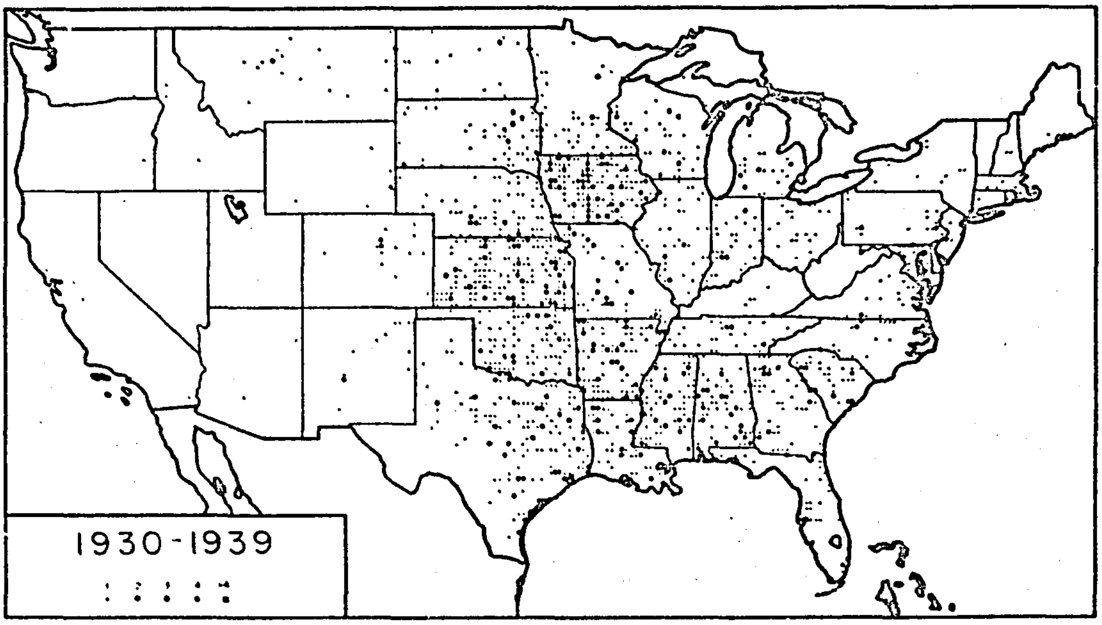


Fig. 3.6 Occurrences of tornadoes during the 1930s.

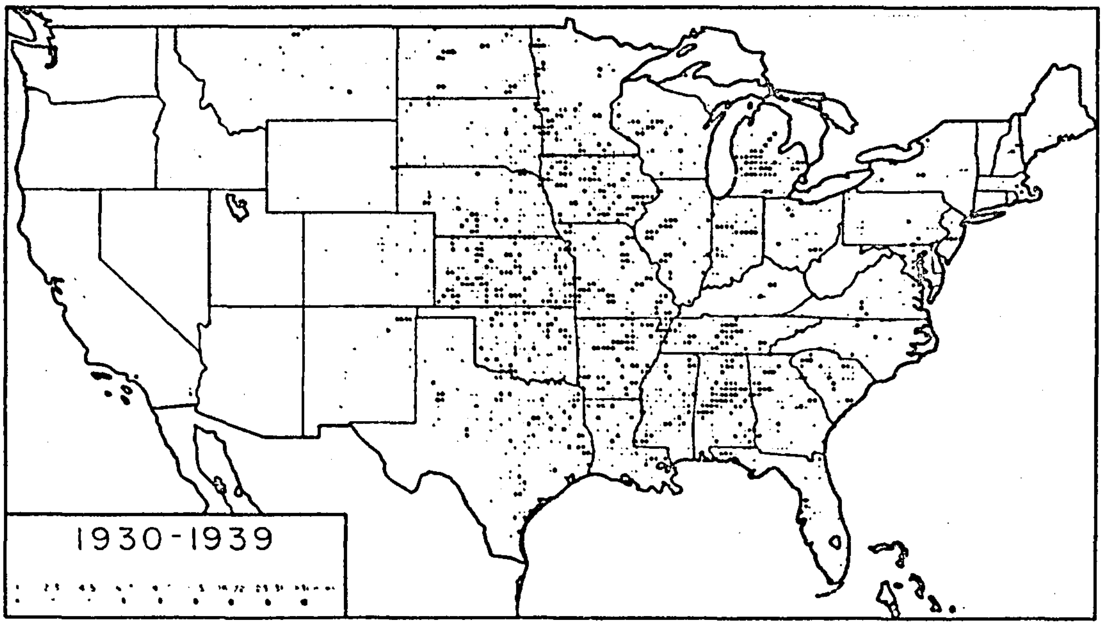


Fig. 3.7 Path lengths of tornadoes during the 1930s.

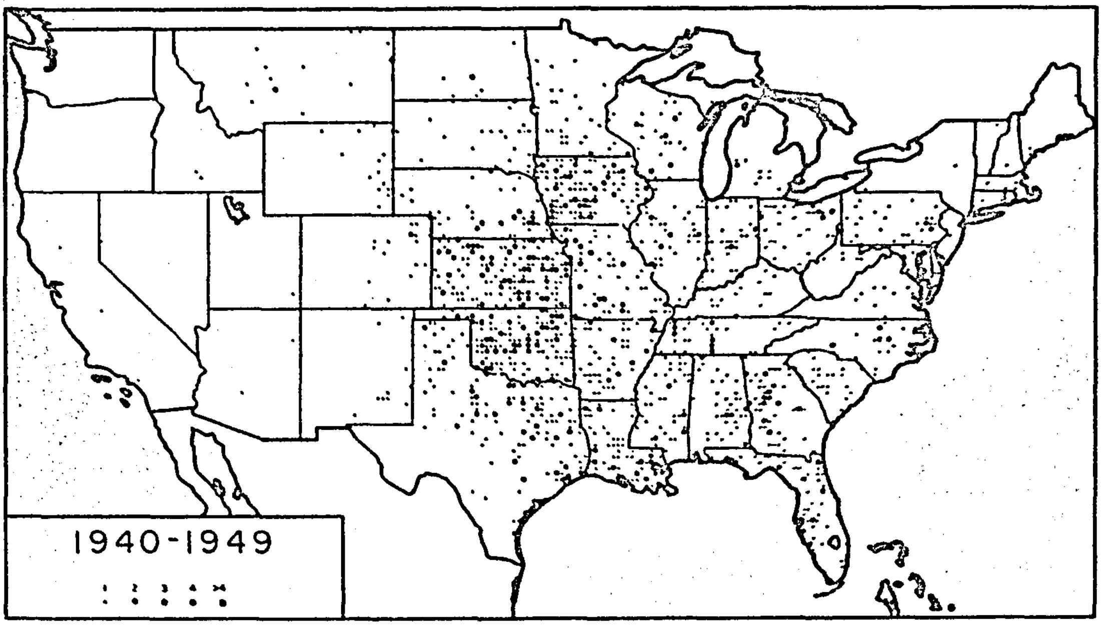


Fig. 3.8 Occurrences of tornadoes during the 1940s.

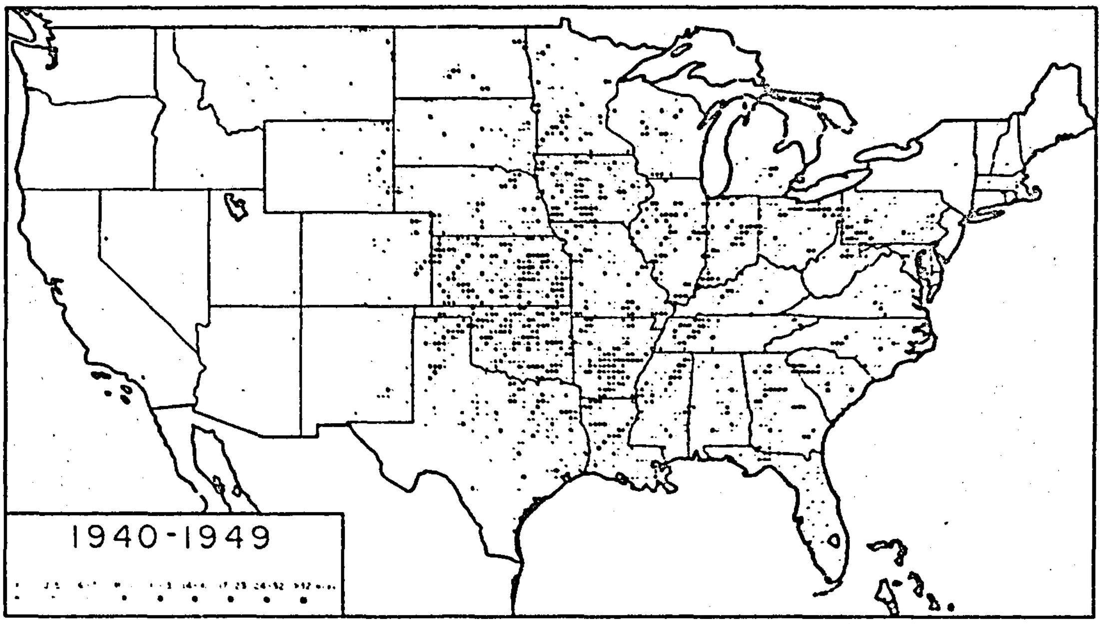


Fig. 3.9 Path lengths of tornadoes during the 1940s.

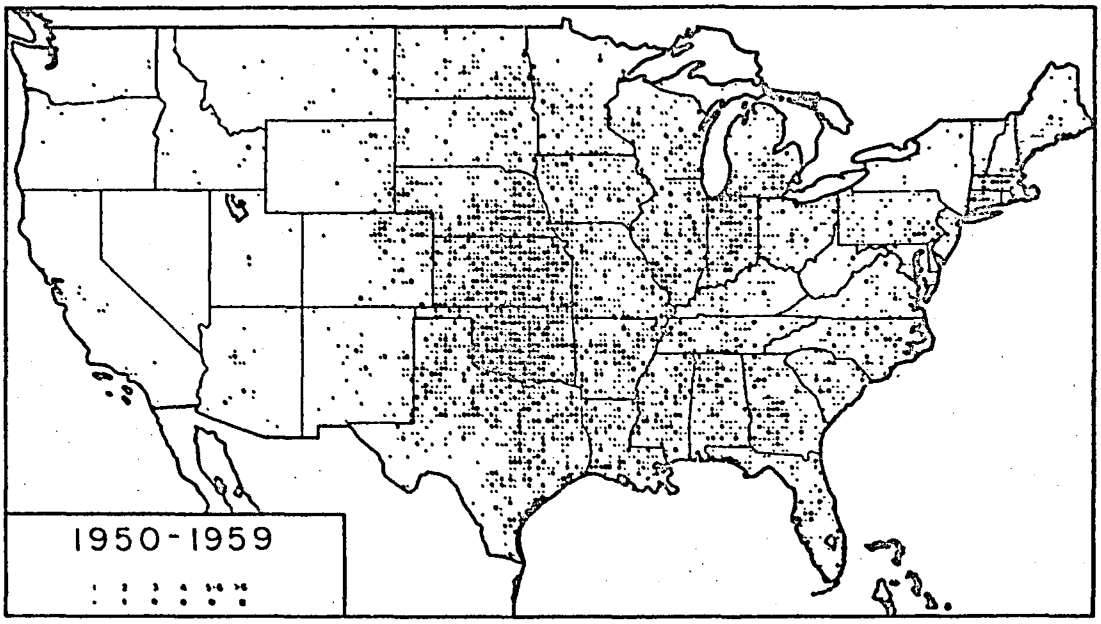


Fig. 3.10 Occurrences of tornadoes during the 1950s.

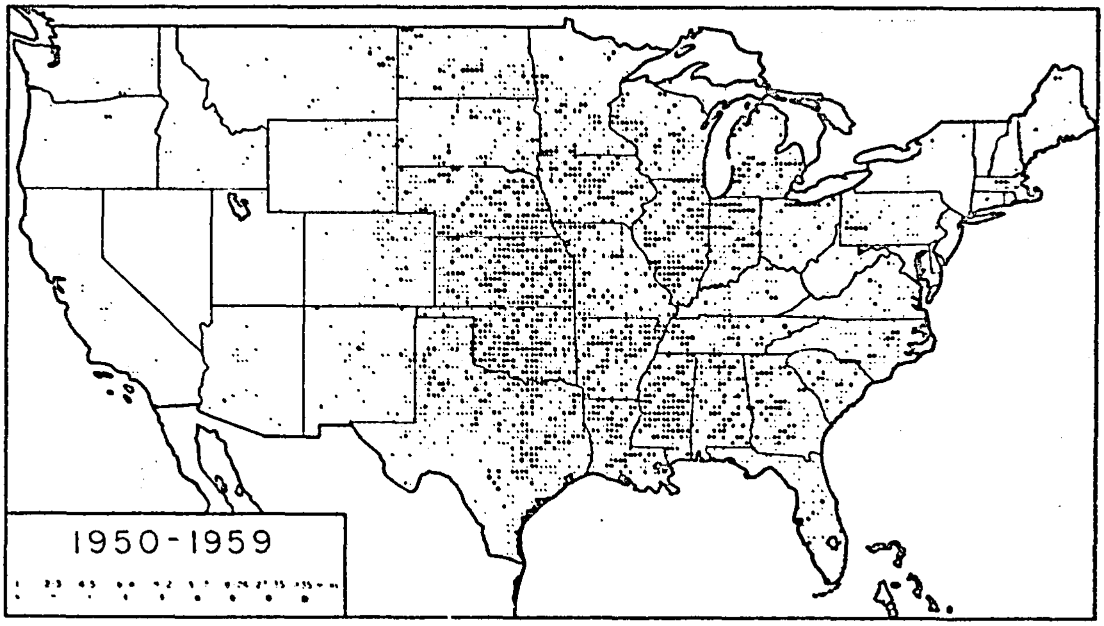


Fig. 3.11 Path lengths of tornadoes during the 1950s.

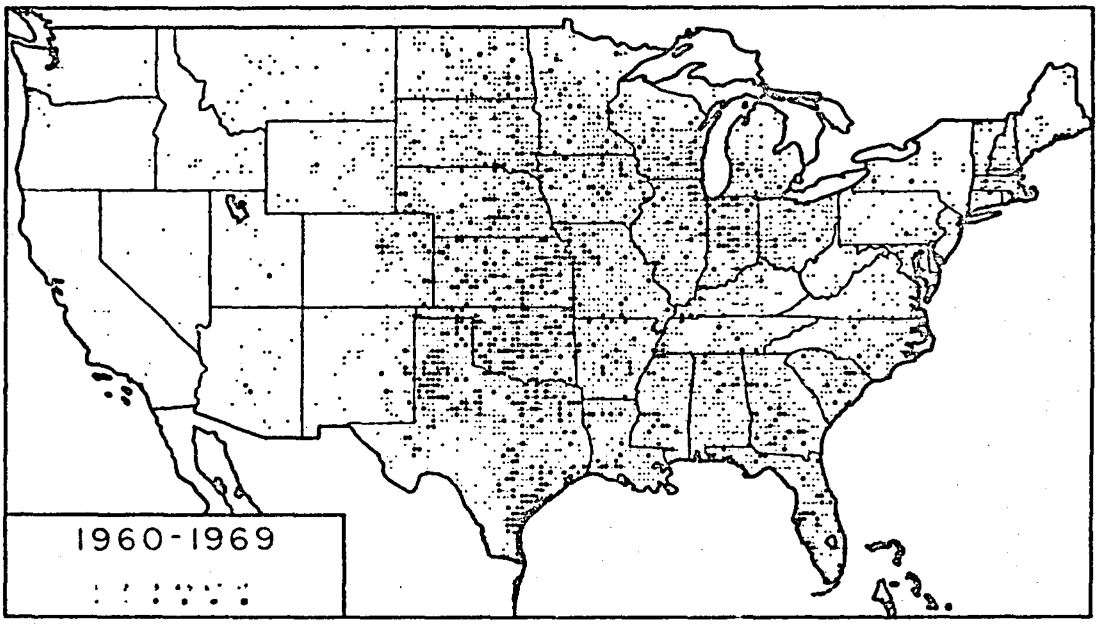


Fig. 3.12 Occurrences of tornadoes during the 1960s.

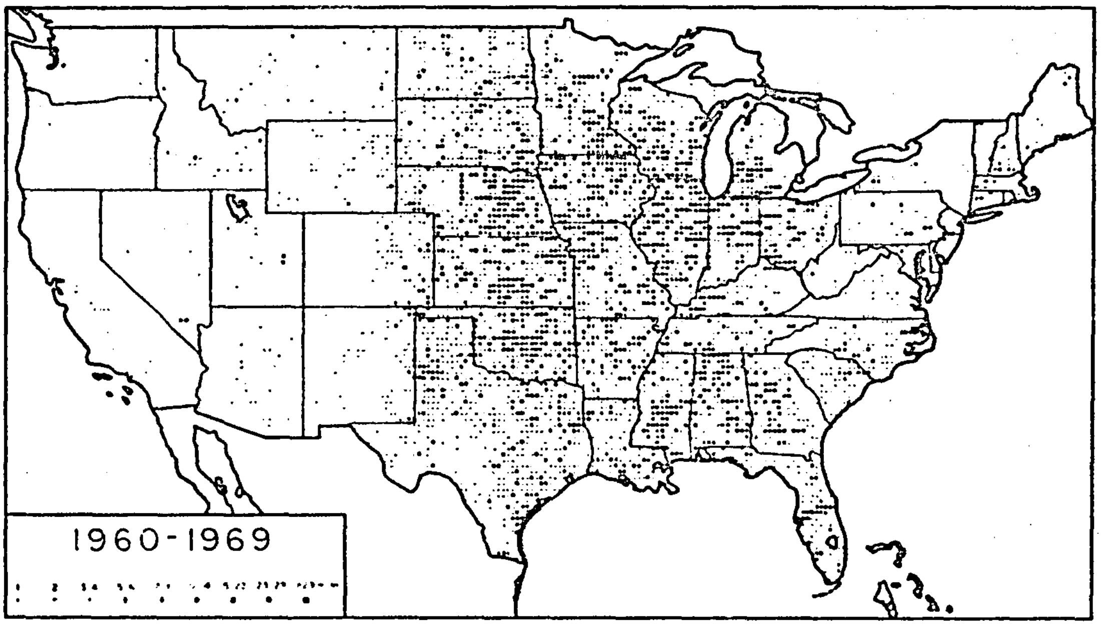


Fig. 3.13 Path lengths of tornadoes during the 1960s.

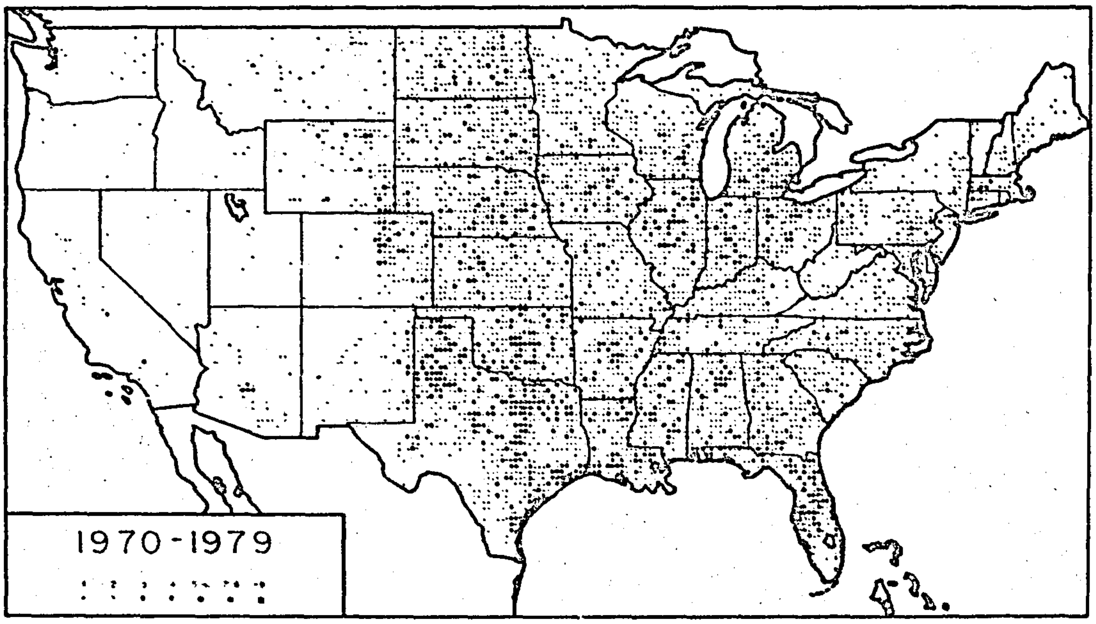


Fig. 3.14 Occurrences of tornadoes during the 1970s.

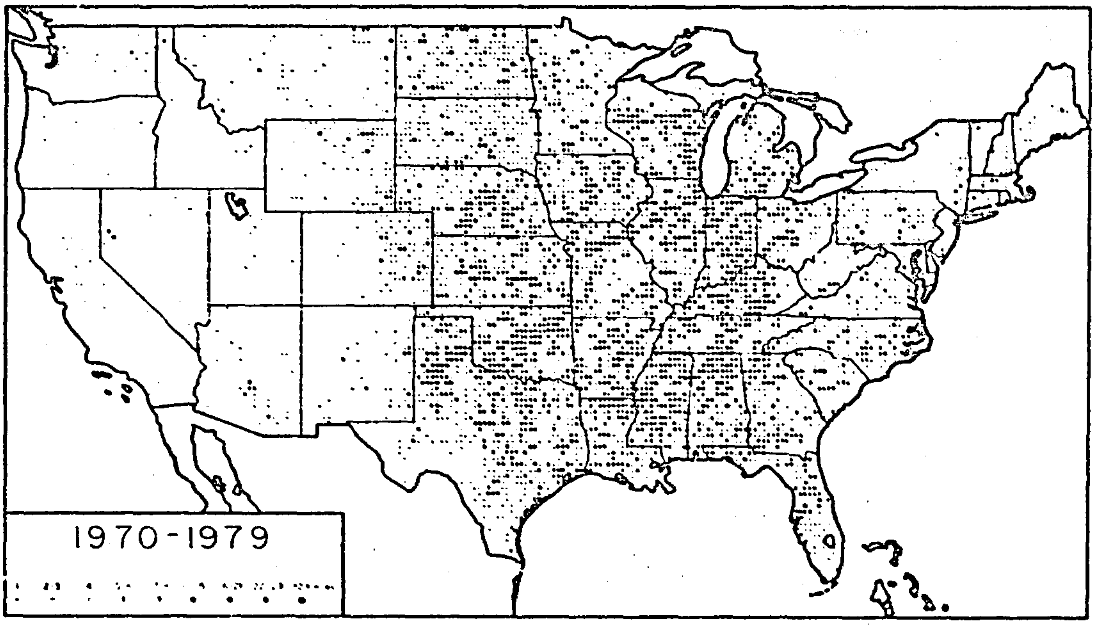


Fig. 3.15 Path lengths of tornadoes during the 1970s.

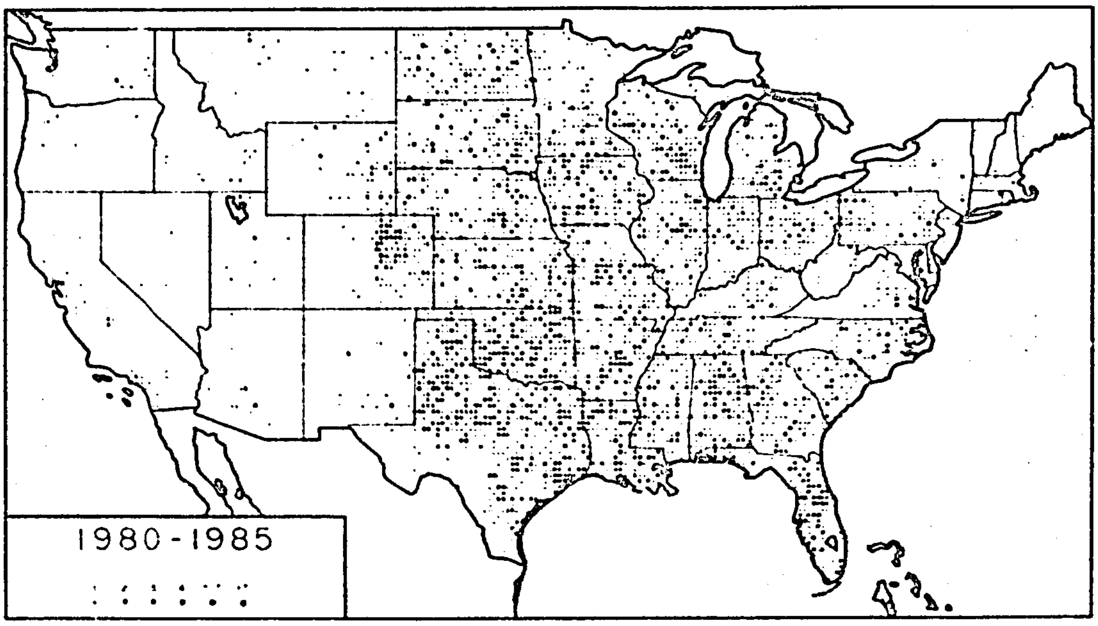


Fig. 3.16 Occurrences of tornadoes during the 1980s.

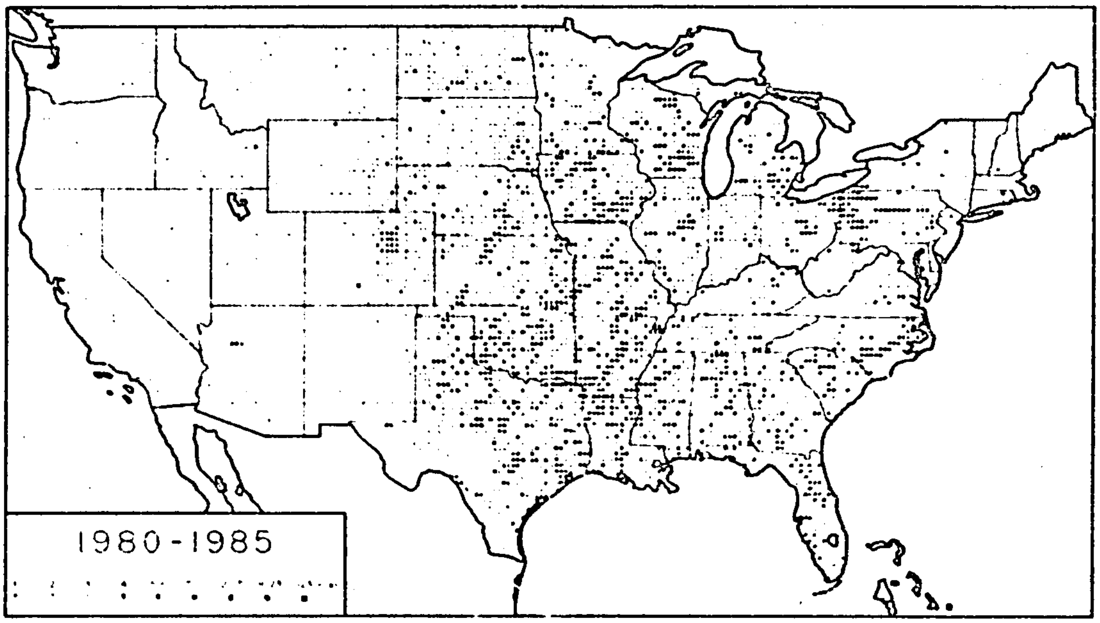


Fig. 3.17 Path lengths of tornadoes during the 1980s.

Chapter Four

Seasonal Variation

Tornadoes occur every month of the year, but their seasonal variation is very large. The peak month for all tornadoes is May and the least occurrence month is January.

4.1 Tornado Occurrences by Month

The peak occurrence month of violent tornadoes is earlier (April) than that of weak tornadoes, which peaks one month later (May). The main reason for this one-month difference in the peak month is that most violent tornadoes are spawned by severe supercell thunderstorms which form most frequently in April. On the other hand, weak tornadoes, in general, are induced by less severe thunderstorms which peak in May when the combined effects of ground heating due to solar radiation and atmospheric dynamics are most favorable.

Table 4.1 presents tornado occurrences by month and by F scale. The seasonal variation of tornado occurrences is also presented in Fig. 4.1 in graphical form. This figure shows that occurrences increase very rapidly from March to May and decrease slowly thereafter.

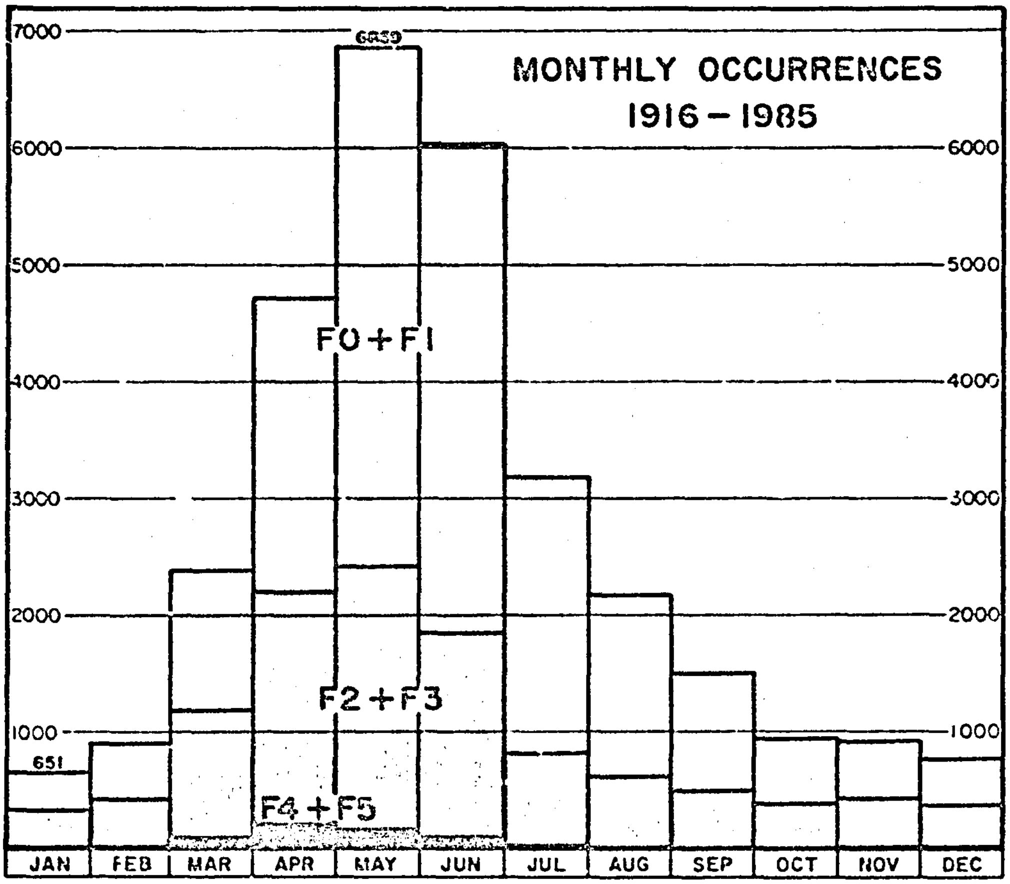


Fig. 4.1 Monthly occurrences of U.S. tornadoes (1916-1985) separated into weak (F0+F1), strong (F2+F3), and violent (F4+F5) tornadoes. Violent tornadoes are shown in black, strong tornadoes in red, and weak tornadoes in blue. The peak month for overall tornadoes is May with 6 859 in 70 years or 98 occurrences per year. However, F4+F5 tornadoes peak in April.

Table 4.1 Monthly occurrences of tornadoes (1916-1985) tabulated as functions of F scale.

Month	F5	F4	F3	F2	F1	F0
January	2	11	102	220	236	80
February	0	18	118	287	363	111
March	8	94	360	729	872	324
April	30	186	636	1349	1624	881
May	24	156	583	1664	2402	2030
June	15	89	373	1369	2212	1973
July	2	21	145	651	1302	1070
August	2	18	96	493	923	653
September	0	16	110	374	582	423
October	2	7	105	282	378	175
November	1	10	131	300	364	111
December	2	14	119	245	316	80
Total	88	640	2878	7963	11574	7911

Table 4.2 Cumulative occurrences of tornadoes computed from Table 4.1. The symbol "+" after each F scale means "or stronger" tornadoes.

Month	F5	F4+	F3+	F2+	F1+	F0+
January	2	13	115	335	571	651
February	0	18	136	423	786	897
March	8	102	462	1191	2063	2387
April	30	216	852	2201	3825	4706
May	24	180	763	2427	4829	6859
June	15	104	477	1846	4058	6031
July	2	23	168	819	2121	3191
August	2	20	116	609	1532	2185
September	0	16	126	500	1082	1505
October	2	9	114	396	774	949
November	1	11	142	442	806	917
December	2	16	135	380	696	776
Total	88	728	3606	11569	23143	31054

4.2 Tornado Path Length by Month

Some tornadoes are on the ground for a very short time, while others leave behind long paths of destruction. Therefore, the total path lengths in each month (monthly path lengths) is more representative than their occurrences (See Tables 4.3 and 4.4 and Fig. 4.2).

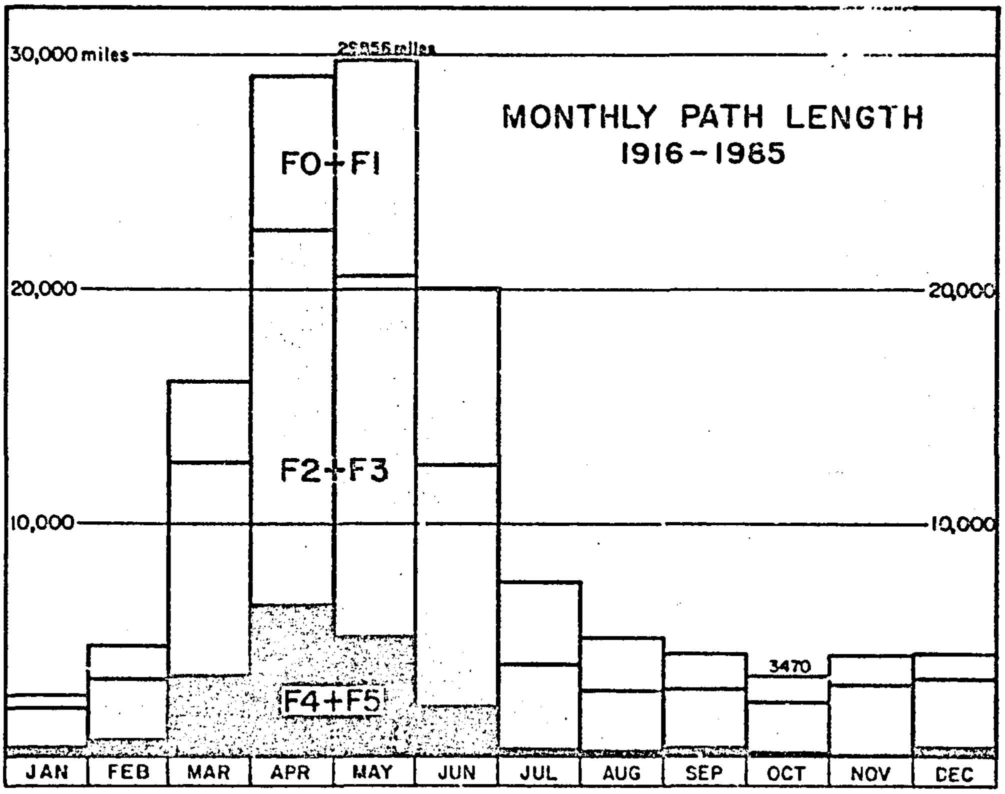


Fig. 4.2 Monthly path length of tornadoes in 70 years, 1916-1985.

Table 4.3 Monthly path lengths of tornadoes (1916-1985) tabulated as functions of F scale.

Month	F5	F4	F3	F2	F1	F0
January	76	377	663	980	496	189
February	0	771	996	1607	1278	111
March	583	2912	3994	5092	2774	663
April	1132	5368	7513	8541	5196	1478
May	867	4262	6040	9452	6738	2497
June	298	1908	3396	6873	5418	2151
July	13	351	1026	2569	2495	1045
August	30	252	674	1901	1673	553
September	0	488	833	1611	1070	439
October	86	177	891	1157	922	237
November	7	142	1350	1634	1128	141
December	34	419	1433	1424	1046	80
Total	3124	17424	28807	42838	30230	9582

Table 4.4 Cumulative path lengths of tornadoes computed from Table 4.3. The symbol "+" after each F scale means "or stronger" tornadoes.

Month	F5	F4+	F3+	F2+	F1+	F0+
January	76	453	1116	2096	2592	2781
February	0	771	1767	3374	4652	4763
March	583	3495	7489	12581	15355	16018
April	1132	6500	14013	22554	27750	29228
May	867	5129	11169	20621	27359	29856
June	298	2206	5602	12475	17893	20044
July	13	364	1390	3959	6454	7499
August	30	282	956	2857	4530	5083
September	0	488	1321	2932	4002	4441
October	86	263	1154	2311	3233	3470
November	7	149	1499	3133	4261	4402
December	34	453	1886	3310	4356	4436
Total	3124	30548	49355	92193	122423	132005

4.3 Tornado Distribution by Month

The following twelve pages present geographic distributions of occurrences (upper charts) and path lengths (lower charts) for each month of the year. Both occurrences and path lengths are coded, based on the statistical distribution of these parameters, so that the printout symbols depict the geographic distribution of tornado activities in the specific month. In order to distinguish tornado occurrences from tornado path lengths, occurrences are printed in blue grid prints while path lengths in red grid prints.

During the first five months of the year, January through May, when relatively long-path tornadoes occur, path-length maps show banded patterns produced by intense tornadoes which move frequently from southwest to northeast. Because tornadoes in the summer months are spawned often by airmass-type storms, path-length maps show little evidence of banded structure. In autumn, the banded patterns are recognized again.

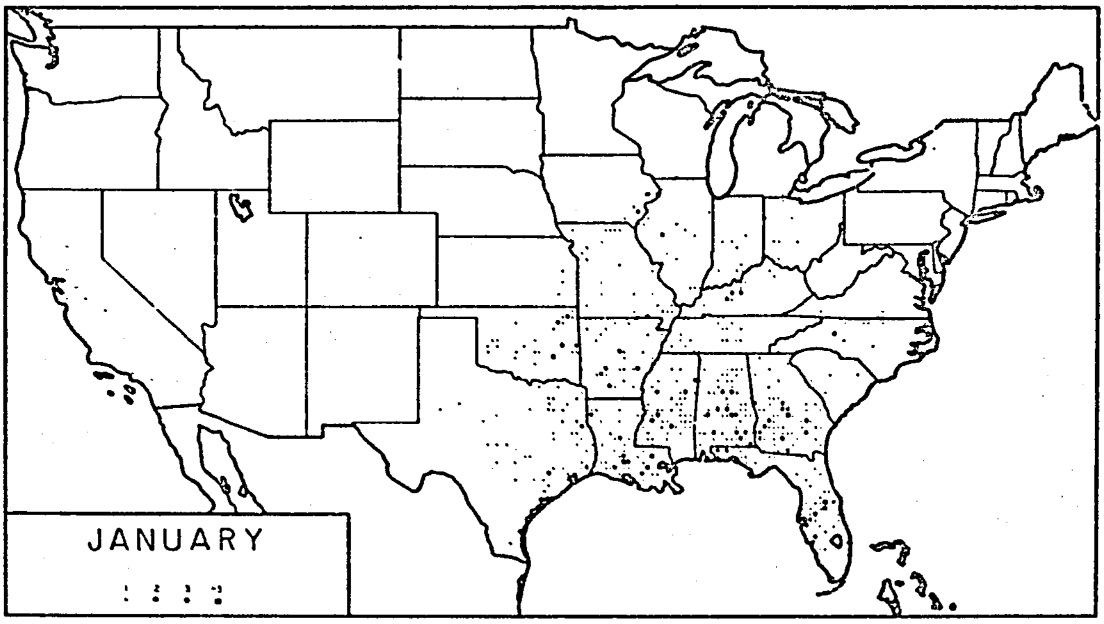


Fig. 4.3 Occurrence of tornadoes in January (1916-1985).

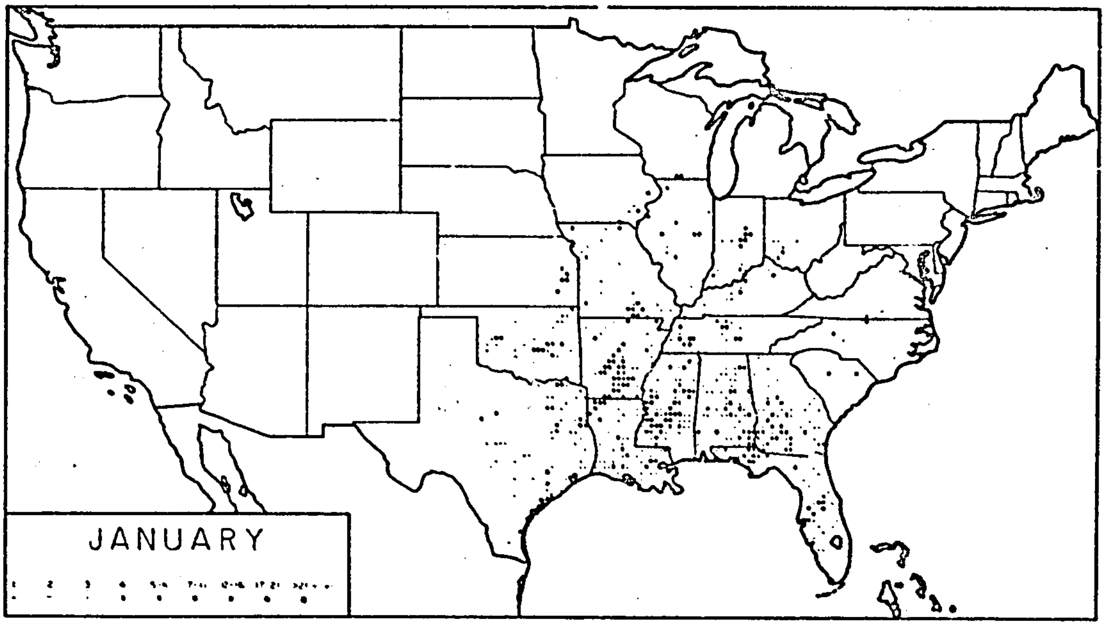


Fig. 4.4 Path length of tornadoes in January (1916-1985).

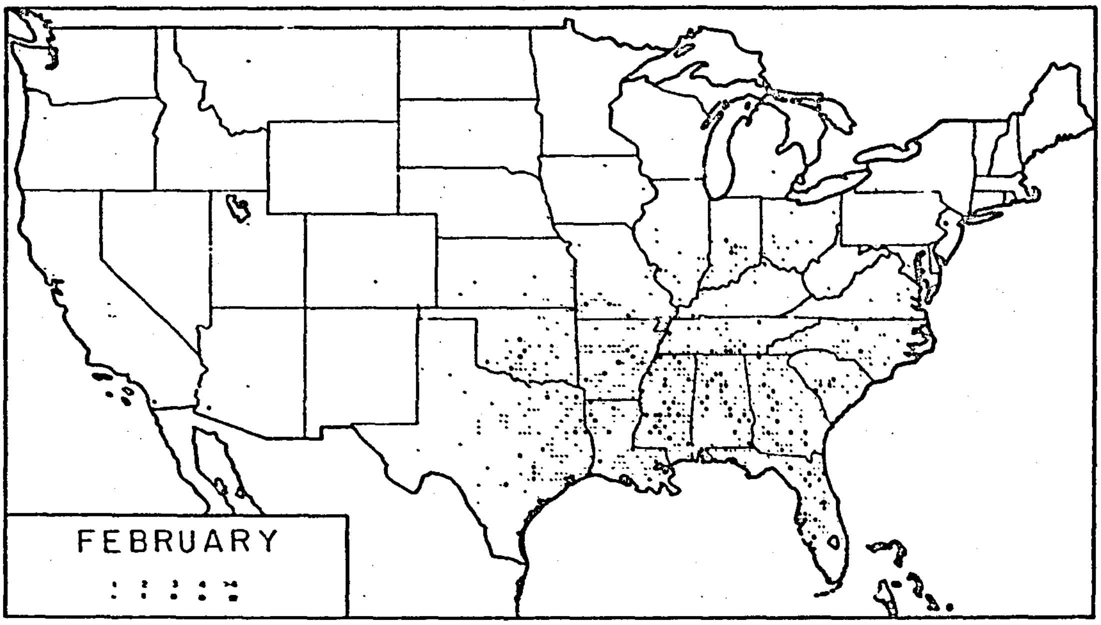


Fig. 4.5 Occurrence of tornadoes in February (1916-1985).

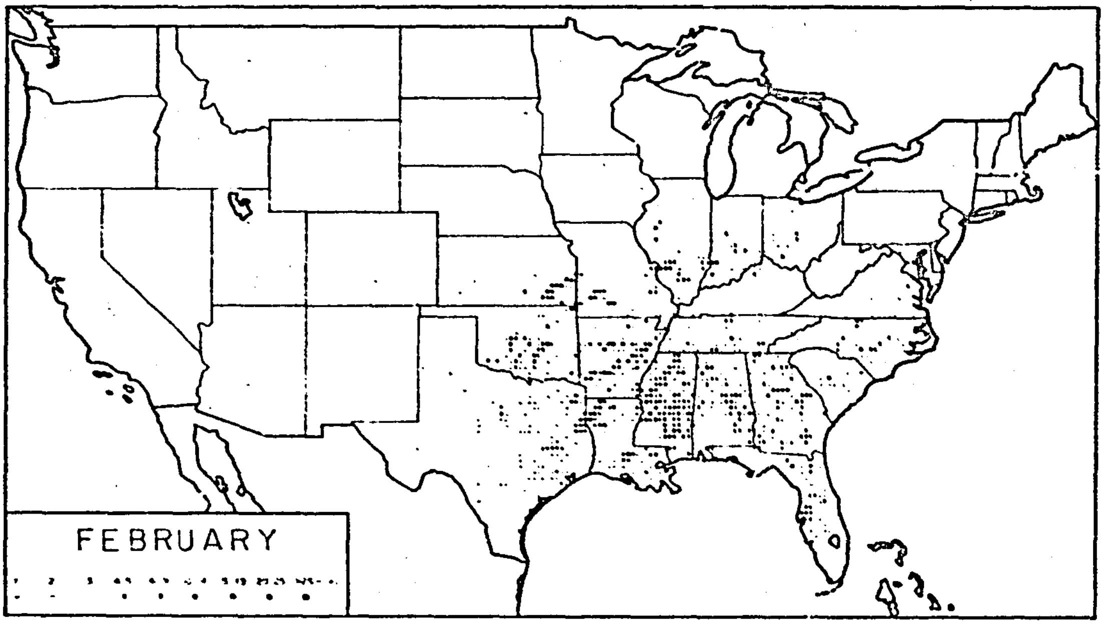


Fig. 4.6 Path length of tornadoes in February (1916-1985).

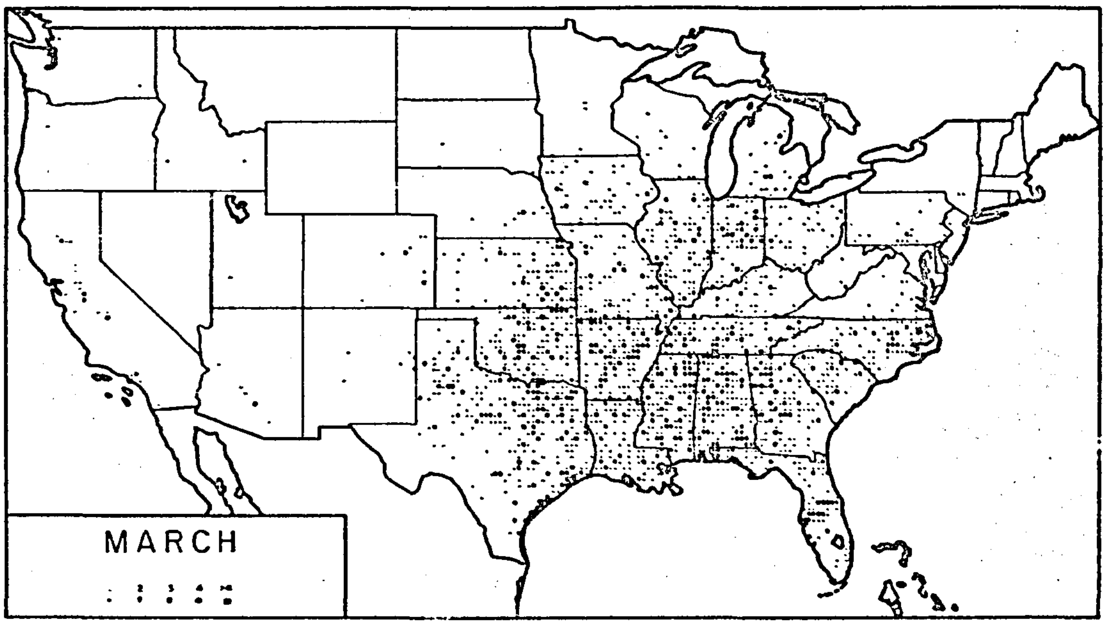


Fig. 4.7 Occurrence of tornadoes in March (1916-1985).

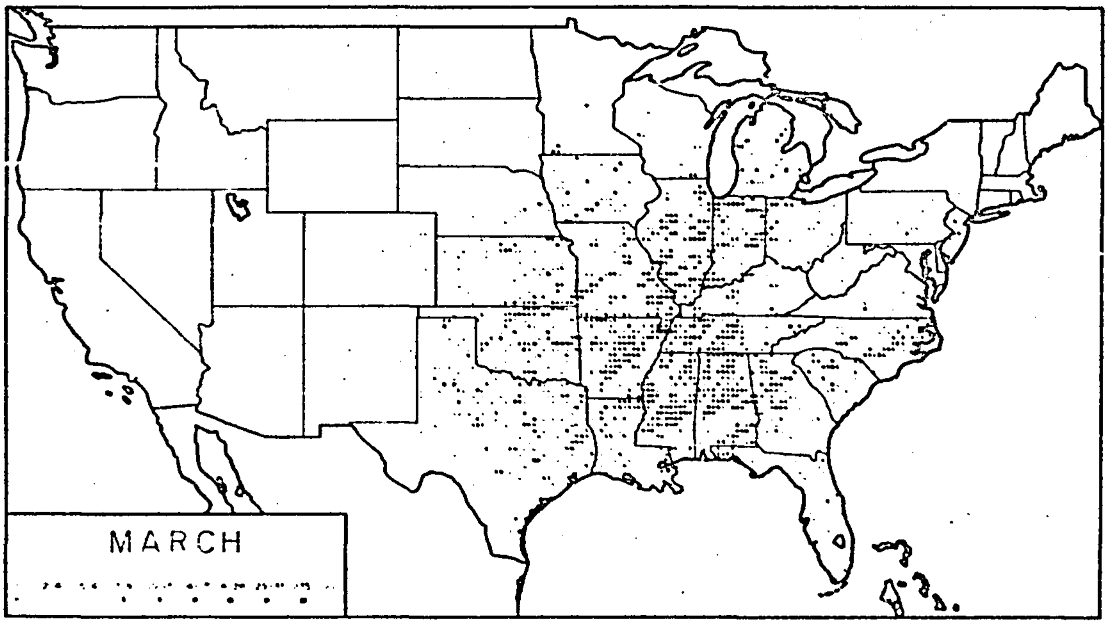


Fig. 4.8 Path length of tornadoes in March (1916-1985).

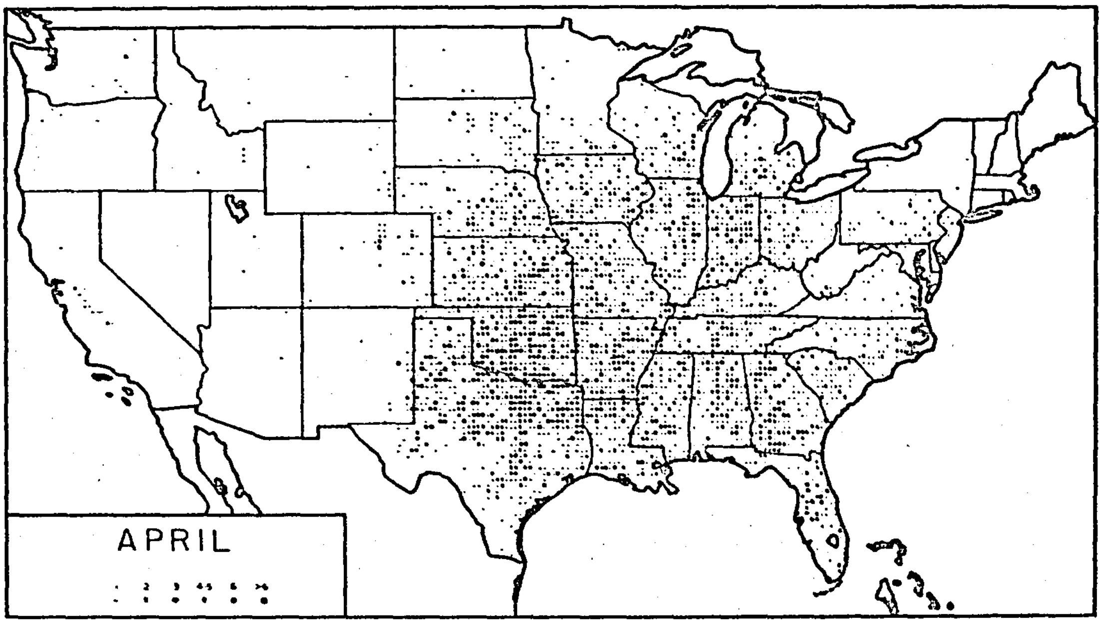


Fig. 4.9 Occurrence of tornadoes in April (1916-1985).

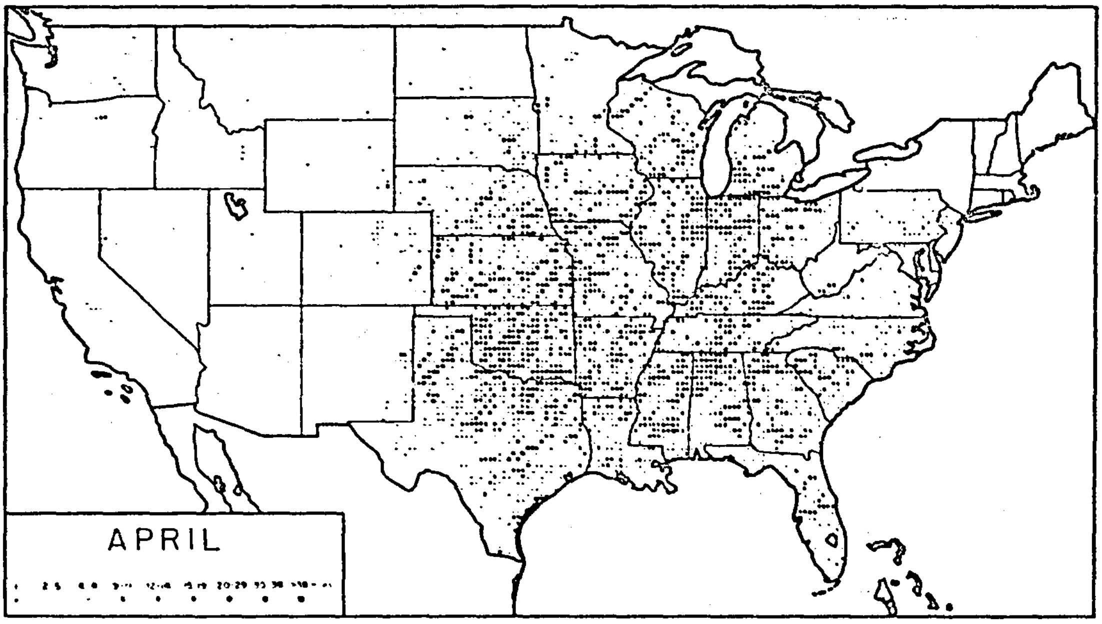


Fig. 4.10 Path length of tornadoes in April (1916-1985).

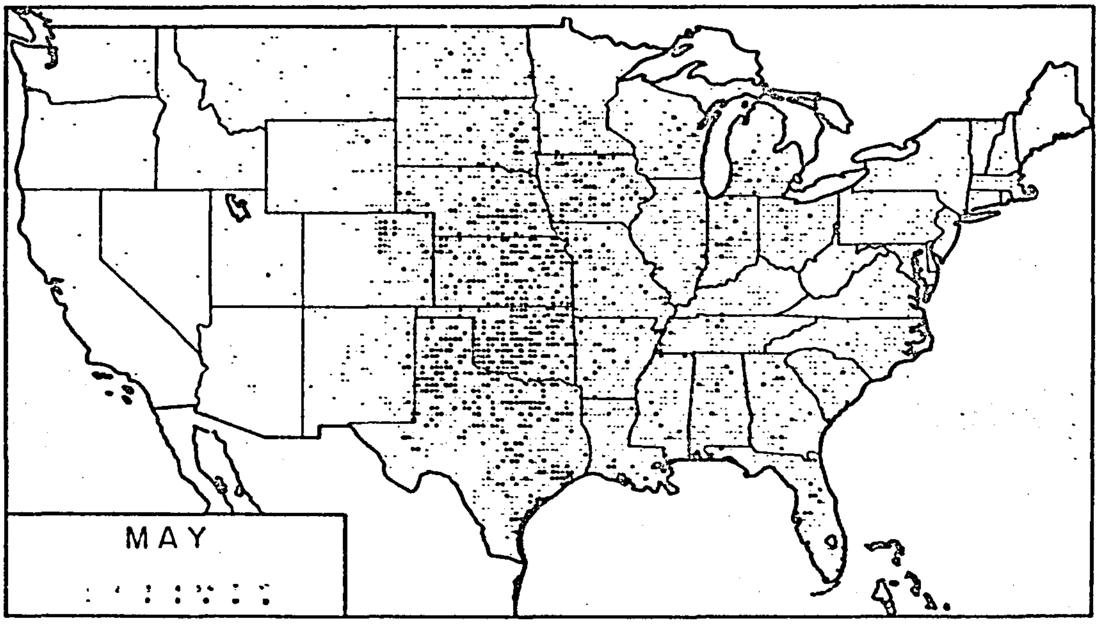


Fig. 4.11 Occurrence of tornadoes in May (1916-1985).

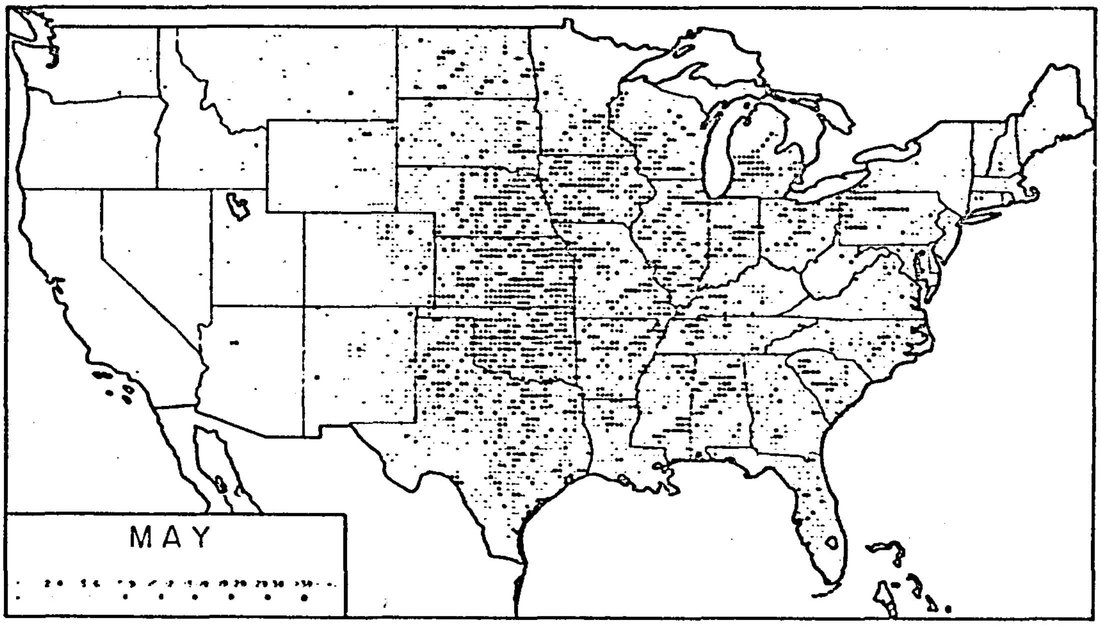


Fig. 4.12 Path length of tornadoes in May (1916-1985).

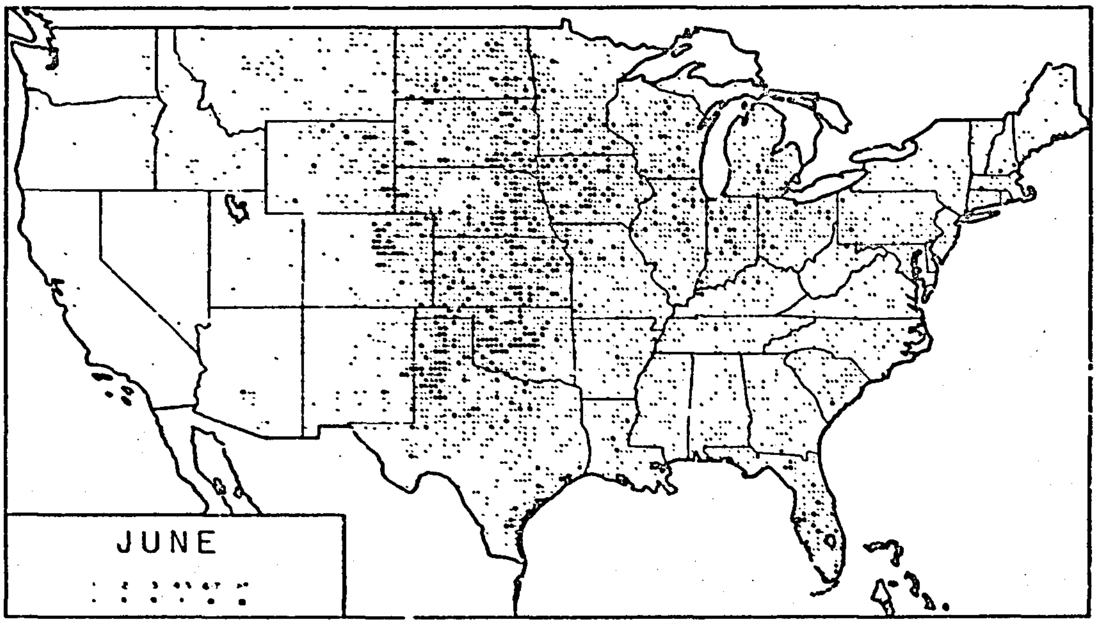


Fig. 4.13 Occurrence of tornadoes in June (1916-1985).

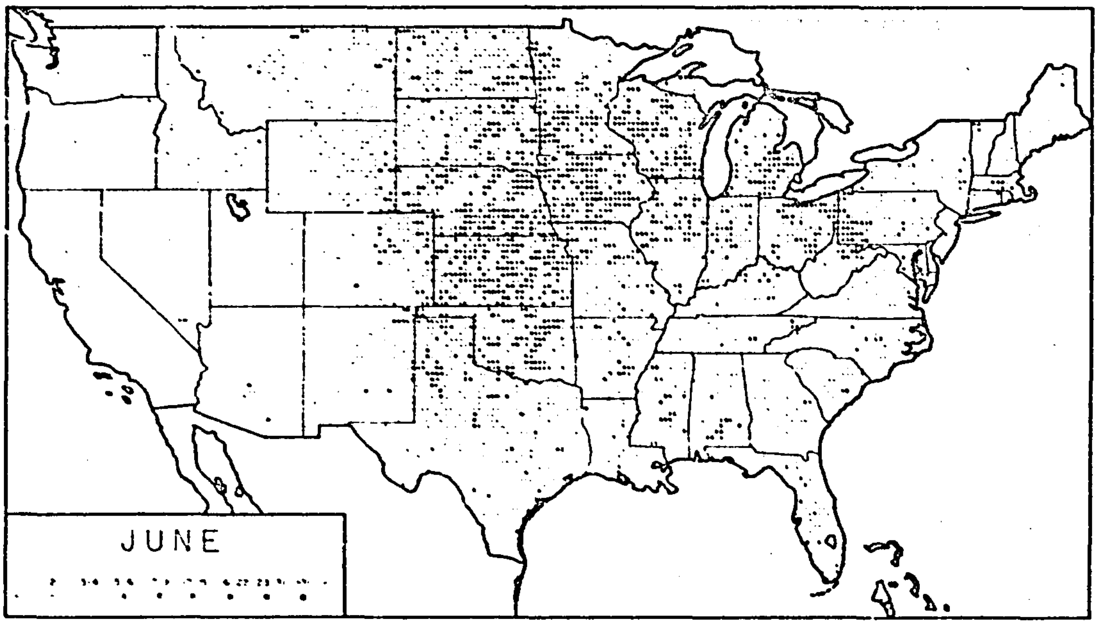


Fig. 4.14 Path length of tornadoes in June (1916-1985).

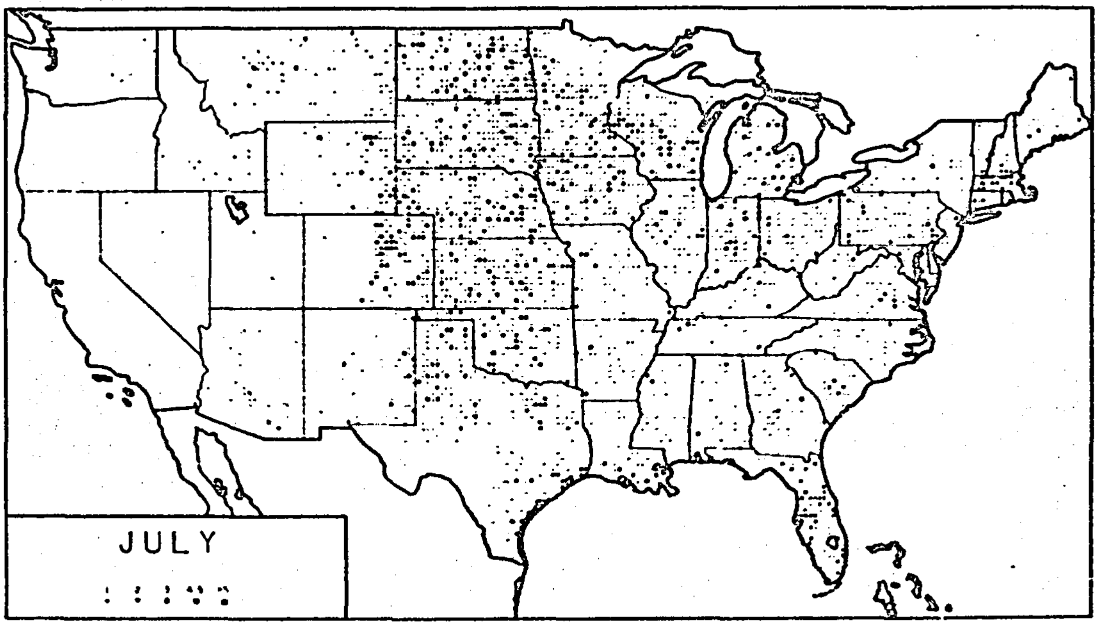


Fig. 4.15 Occurrence of tornadoes in July (1916-1985).

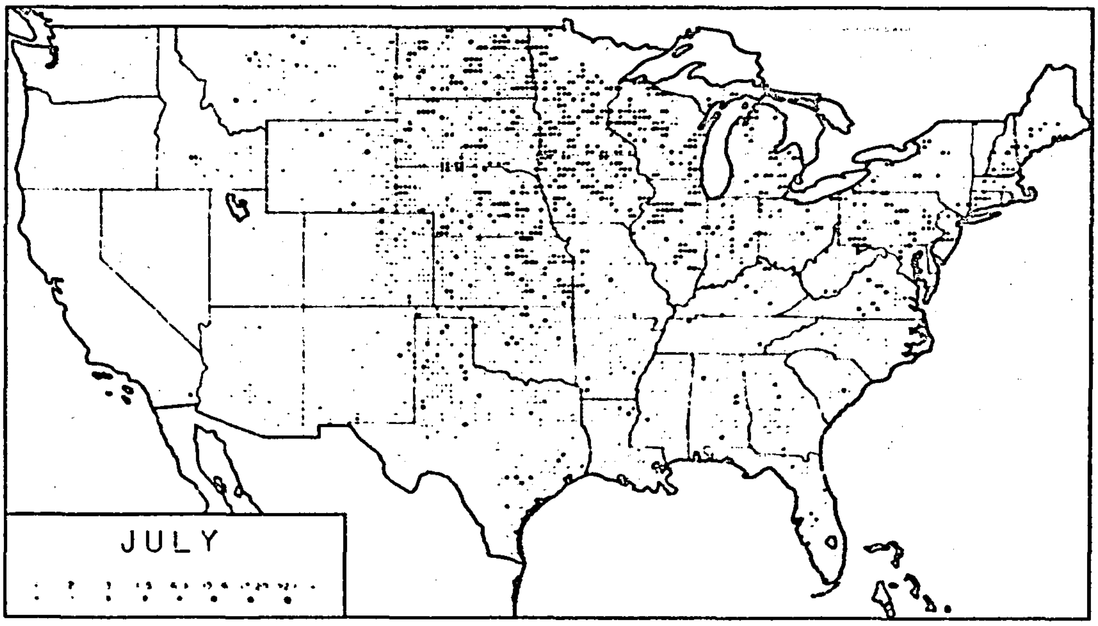


Fig. 4.16 Path length of tornadoes in July (1916-1985).

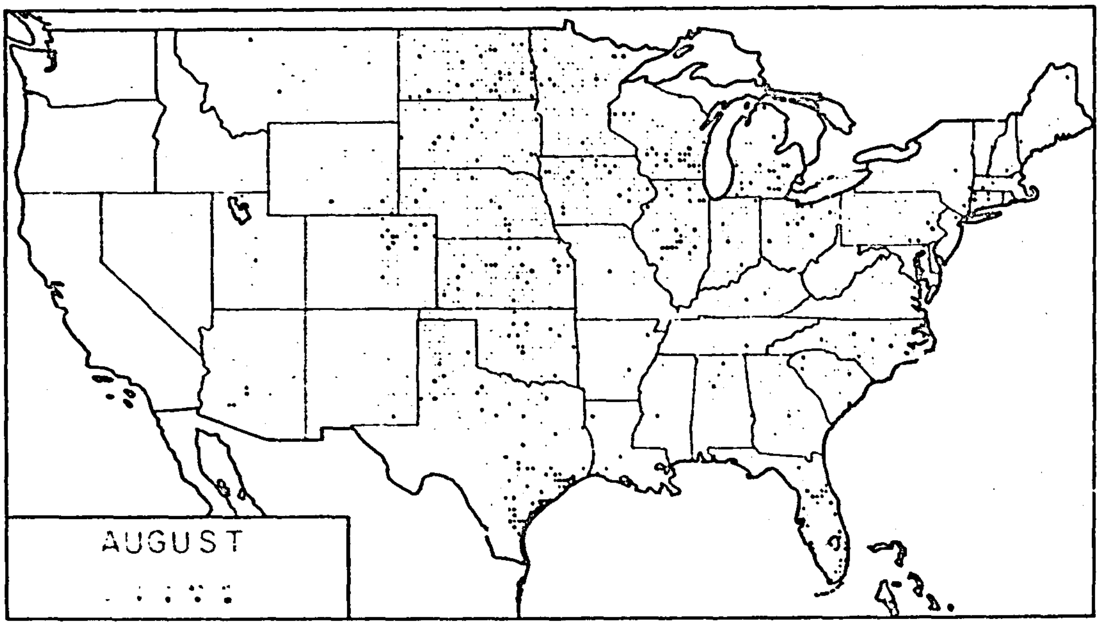


Fig. 4.17 Occurrence of tornadoes in August (1916-1985).

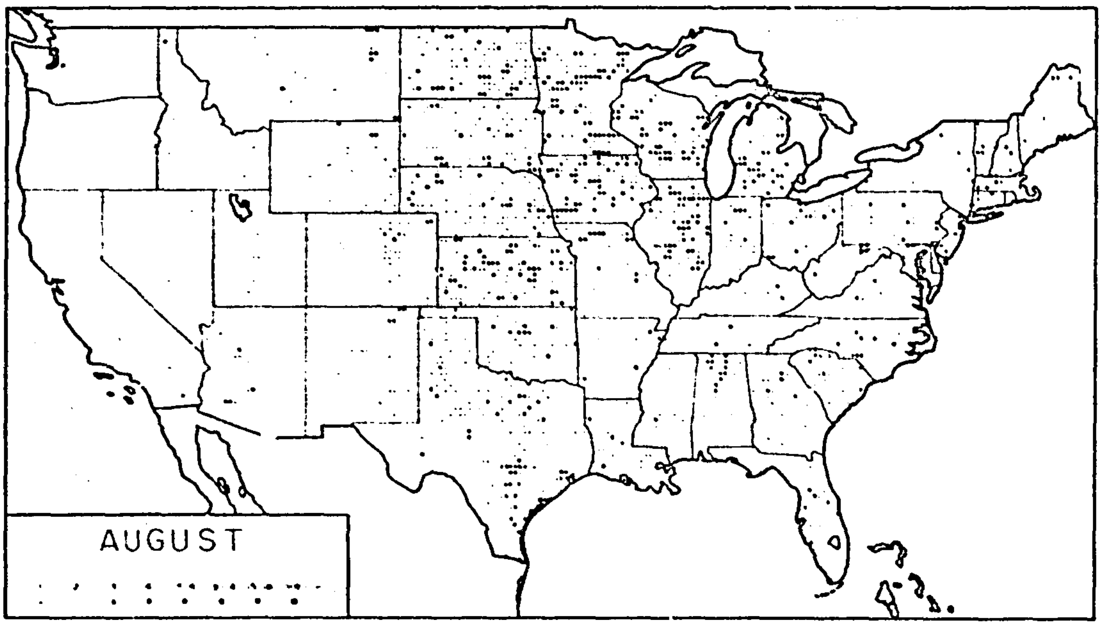


Fig. 4.18 Path length of tornadoes in August (1916-1985).

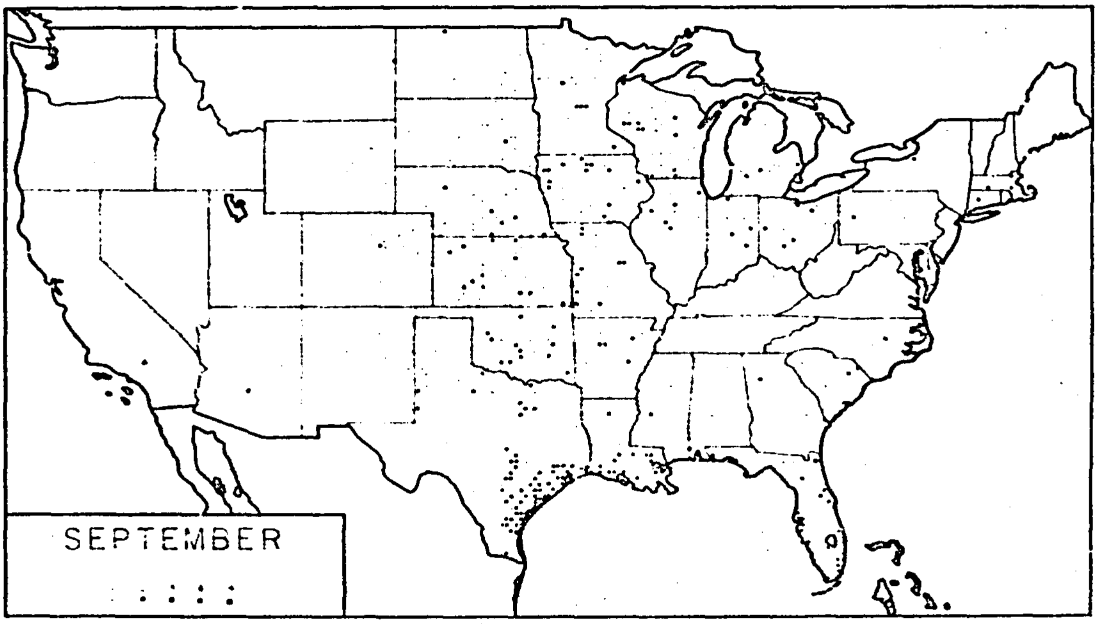


Fig. 4.19 Occurrence of tornadoes in September (1916-1985).

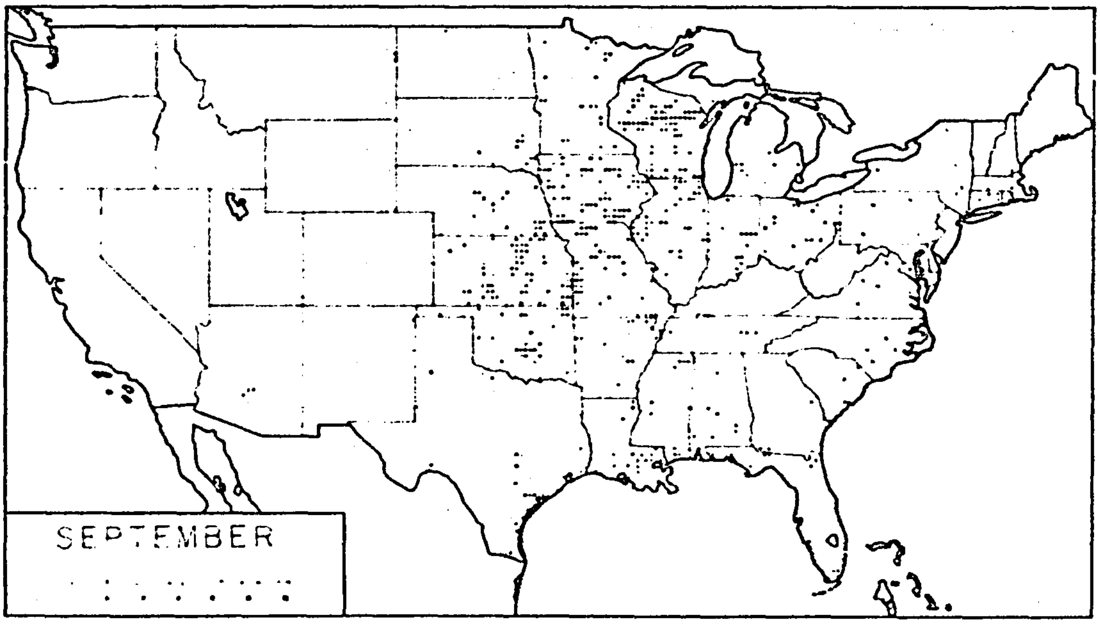


Fig. 4.20 Path length of tornadoes in September (1916-1985).

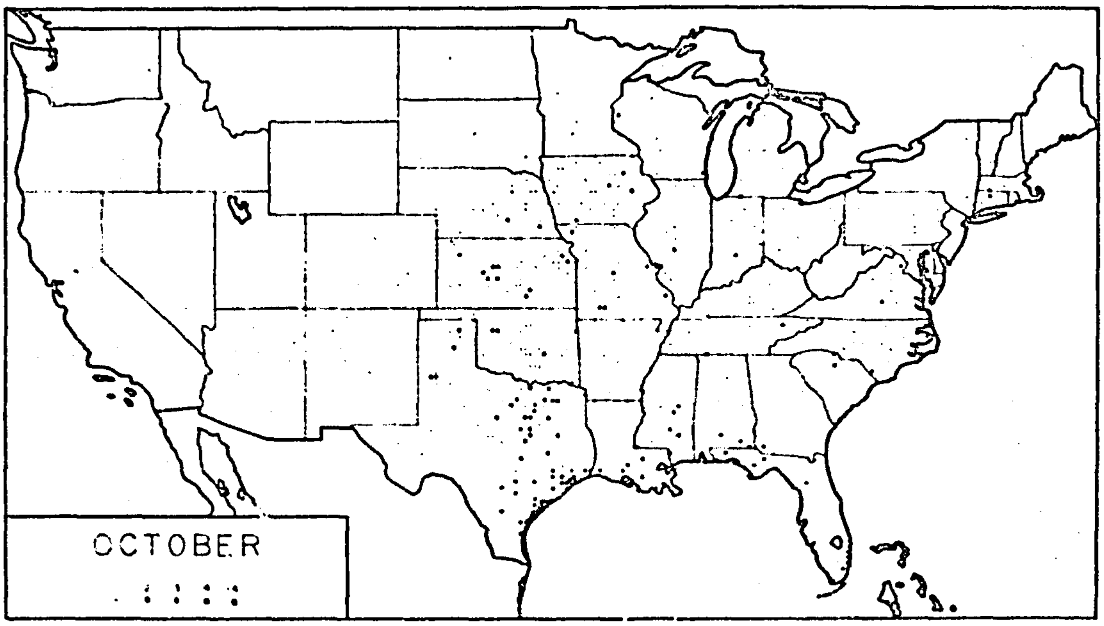


Fig. 4.21 Occurrence of tornadoes in October (1916-1985).

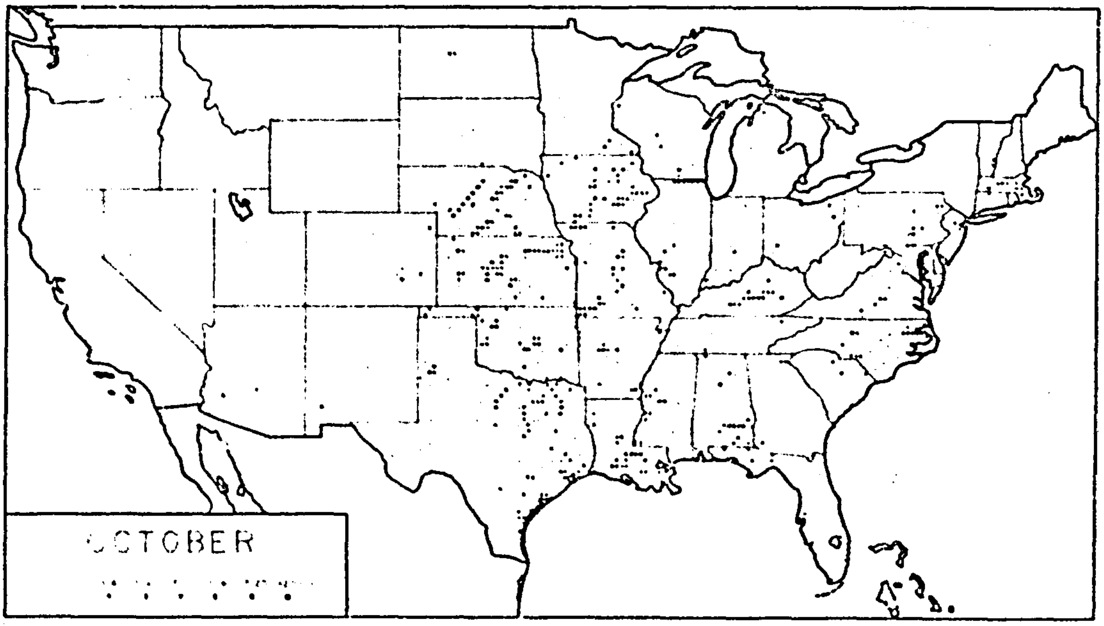


Fig. 4.22 Path length of tornadoes in October (1916-1985).

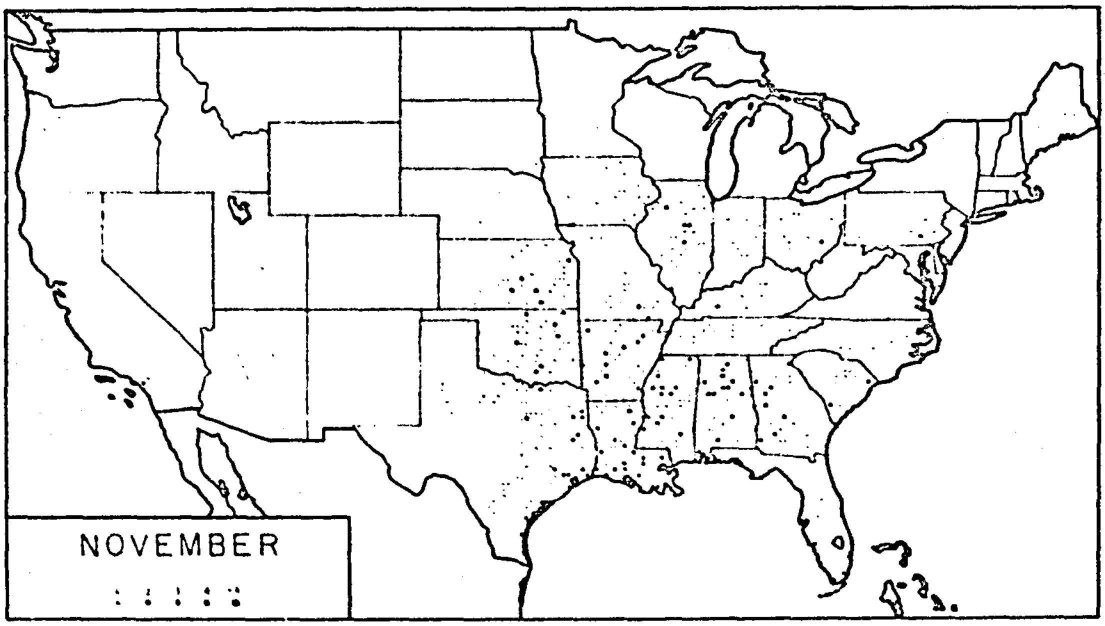


Fig. 4.23 Occurrence of tornadoes in November (1916-1985).

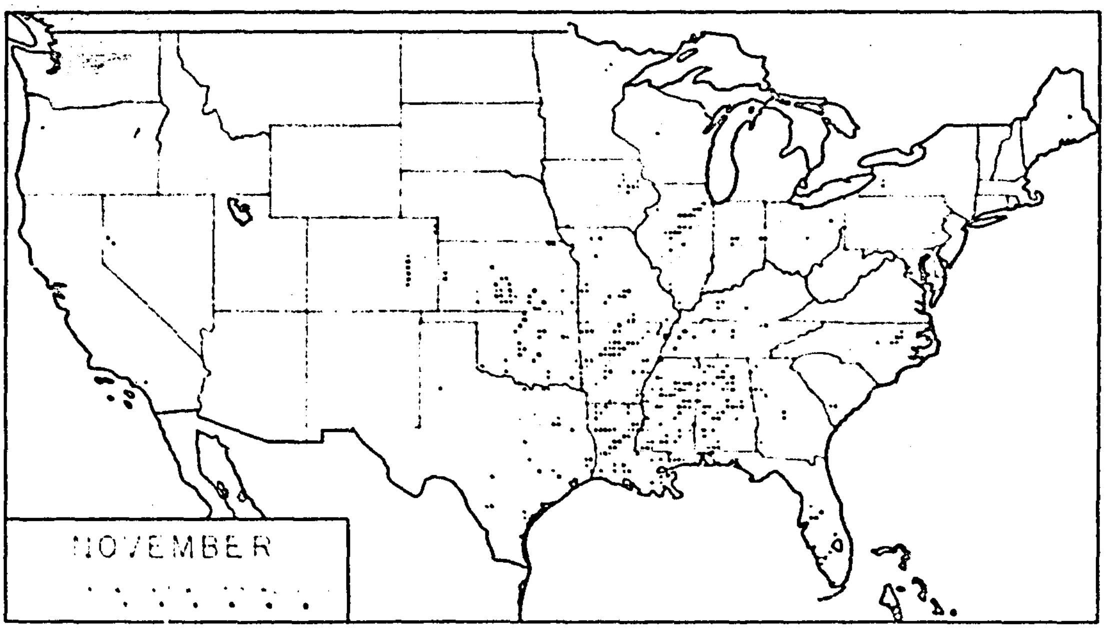


Fig. 4.24 Path length of tornadoes in November (1916-1985).

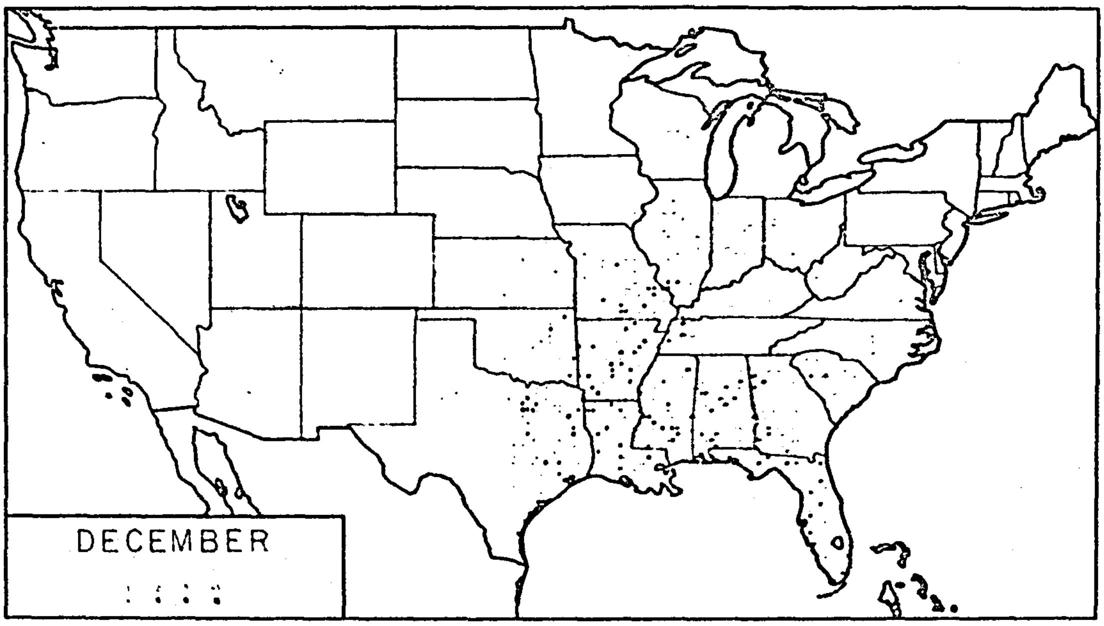


Fig. 4.25 Occurrence of tornadoes in December (1916–1985).

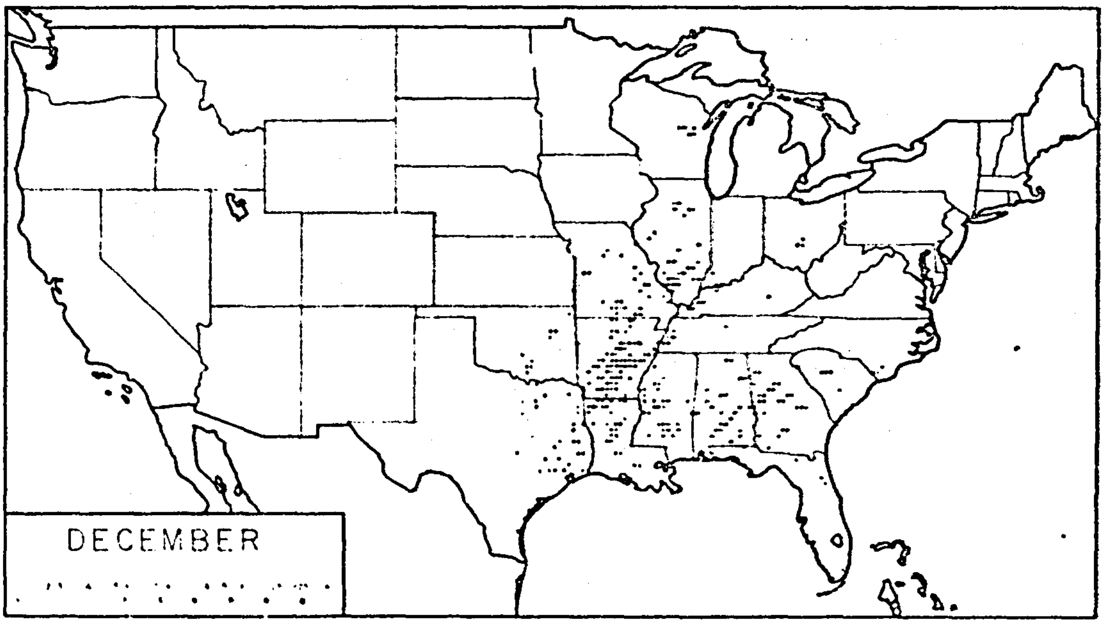


Fig. 4.26 Path length of tornadoes in December (1916–1985).

Chapter Five

Diurnal Variation

The contiguous United States, extending between 80°W and 120°W, is divided into four time zones, Eastern, Central, Mountain, and Pacific. These time zones are separated by irregular zone boundaries extending, more or less, in a north-to-south direction. In order to avoid jumps in the occurrence and path length data along these time zone boundaries, all tornado times are converted into Central Standard Time (CST). Because of this conversion, up to two hours should be added or subtracted in order to determine tornado activities at a given local time.

5.1 Hourly Occurrences

The diurnal variation of hourly occurrences peaks between 1700 and 1800 CST, reaching 3,252 occurrences in 70 years (46 per year) as shown in Fig. 5.1. The minimum occurrence hour is between 0500 and 0600 CST, with 324 occurrences (5 per year). This is why the National Severe Storms Forecast Center begins the tornado-counting day at 0600 CST. The trend of variation by F scale remains unchanged, however, occurrences of F5 tornadoes in the early morning hours are so insignificant that no F5 tornadoes were reported during 0100-0200, 0300-0700, and 1100-1200 CST.

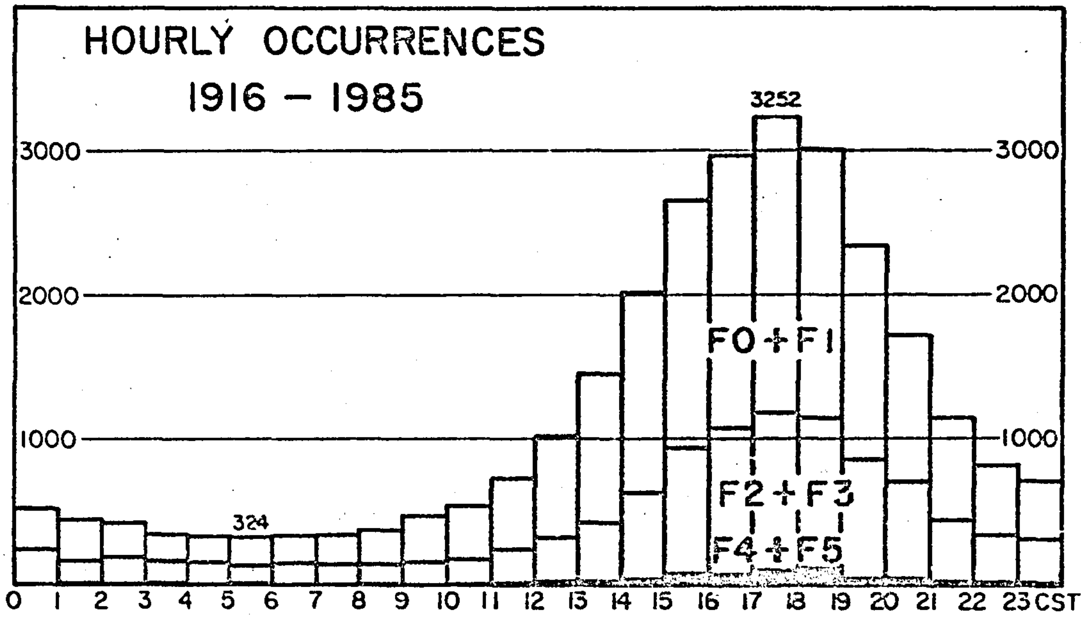


Fig. 5.1 Diurnal variation of hourly occurrences of U.S. tornadoes, 1916-1985. Three-color shadings denote weak (F0+F1) tornadoes in blue, strong (F2+F3) tornadoes in red, and violent (F4+F5) tornadoes in black. The time of maximum tornado hazard is between 5 and 6 p.m. which is approximately three (3) hours later than the peak activity time of microbursts. Refer to Fig. 4.25 (p69) of "The Downburst" by the author.

Table 5.1 Hourly occurrences of tornadoes in 70 years, 1916-1985, tabulated by individual F scale. Occurrence hours of all tornadoes are in CST.

Hour (CST)	F5	F4	F3	F2	F1	F0
0000-0100	2	7	56	192	173	91
0100-0200	0	6	47	139	192	73
0200-0300	1	4	51	143	177	44
0300-0400	0	6	45	119	131	51
0400-0500	0	4	40	119	126	50
0500-0600	0	6	36	87	144	51
0600-0700	0	4	42	114	130	50
0700-0800	2	2	35	100	156	57
0800-0900	2	3	39	110	156	74
0900-1000	2	2	28	130	206	108
1000-1100	1	4	36	140	212	158
1100-1200	0	10	61	166	265	226
1200-1300	2	16	67	238	388	302
1300-1400	4	16	122	291	609	433
1400-1500	13	36	140	450	768	625
1500-1600	14	73	215	654	956	774
1600-1700	9	71	260	757	1128	761
1700-1800	7	98	326	768	1173	880
1800-1900	5	103	300	758	1083	776
1900-2000	11	39	245	599	843	632
2000-2100	5	52	196	458	556	460
2100-2200	4	28	118	311	409	303
2200-2300	1	14	104	240	298	178
2300-2400	1	13	77	220	259	151
0000-2400	86	617	2686	7303	10538	7308

Table 5.2 Hourly occurrences of tornadoes with specific F scale or stronger intensities. F3+ means F3 or stronger tornadoes and F0+, F0 or stronger (F0+F1+F2+F3+F4+F5) tornadoes. Fig. 5.1 was constructed by separating tornado intensities into weak, strong, and violent.

Hour (CST)	F5	F4+	F3+	F2+	F1+	F0+
0000-0100	2	9	65	257	430	521
0100-0200	0	6	53	192	384	457
0200-0300	1	5	56	199	376	420
0300-0400	0	6	51	170	301	352
0400-0500	0	4	44	163	289	339
0500-0600	0	6	42	129	273	324
0600-0700	0	4	46	160	290	340
0700-0800	2	4	39	139	295	352
0800-0900	2	5	44	154	310	384
0900-1000	2	4	32	162	368	476
1000-1100	1	5	41	181	393	551
1100-1200	0	10	71	237	502	728
1200-1300	2	18	85	323	711	1013
1300-1400	4	20	142	433	1042	1475
1400-1500	13	49	189	639	1407	2032
1500-1600	14	87	302	956	1912	2686
1600-1700	9	80	340	1097	2225	2986
1700-1800	7	105	431	1199	2372	3252
1800-1900	5	108	408	1166	2249	3025
1900-2000	11	50	295	894	1737	2369
2000-2100	5	57	253	711	1267	1727
2100-2200	4	32	150	461	870	1173
2200-2300	1	15	119	359	657	835
2300-2400	1	14	91	311	570	721
0000-2400	86	703	3389	10692	21230	28538

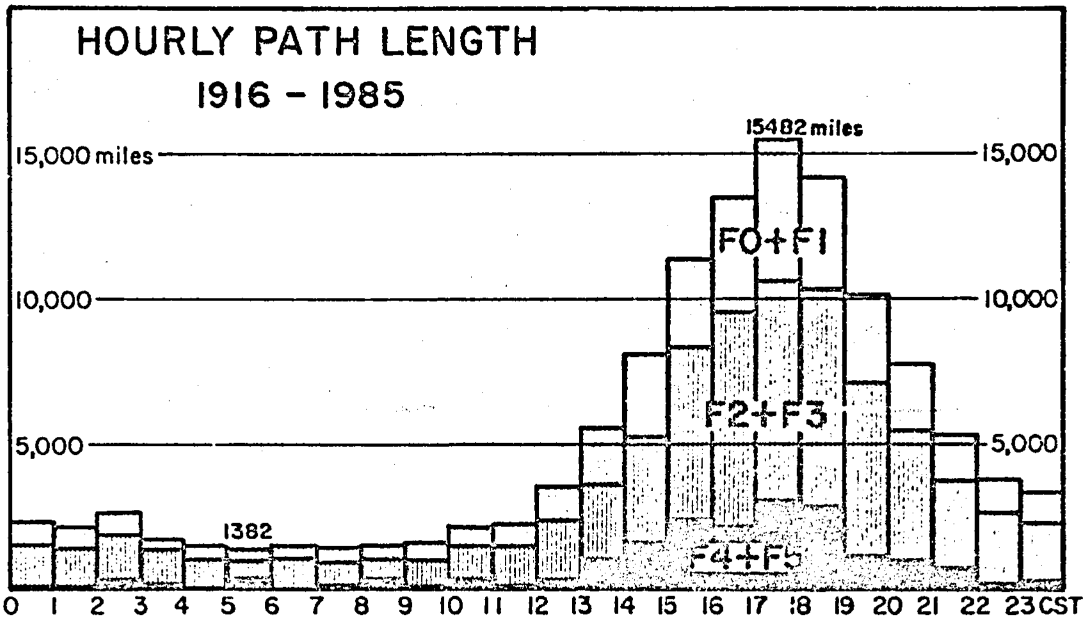


Fig. 5.2 Graphical presentation of the hourly path length given in Table 5.4. Path lengths are colored according to tornado intensities, weak (F0+F1) in blue, strong (F2+F3) in red, and violent (F4+F5) in black.

Table 5.3 Hourly path lengths left behind by various F scale tornadoes during the 70-year period, 1916-1985. These path lengths in miles were computed by adding the path length of each tornado at the occurrence (touchdown) time and rounding up to the next higher mile.

Hour (CST)	F5	F4	F3	F2	F1	F0
0000-0100	29	174	441	891	635	148
0100-0200	0	112	479	836	642	87
0200-0300	75	241	742	834	631	96
0300-0400	0	251	441	694	335	42
0400-0500	0	80	277	649	421	47
0500-0600	0	359	221	404	337	61
0600-0700	0	36	608	458	339	59
0700-0800	58	152	232	478	497	65
0800-0900	86	191	204	586	335	86
0900-1000	59	35	251	667	490	111
1000-1100	82	359	267	772	456	185
1100-1200	0	196	612	661	572	199
1200-1300	78	268	525	1498	965	262
1300-1400	464	550	1189	1480	1327	538
1400-1500	489	1152	1184	2420	2077	760
1500-1600	326	2081	2310	3613	2143	871
1600-1700	205	1985	2806	4553	2888	1020
1700-1800	281	2775	3328	4270	3589	1239
1800-1900	137	2709	3198	4235	2873	1033
1900-2000	233	907	2779	3197	2310	693
2000-2100	79	923	1643	2800	1787	606
2100-2200	132	597	1365	1727	1141	388
2200-2300	43	200	1196	1207	922	218
2300-2400	36	273	747	1290	809	216
0000-2400	2888	16598	27038	40216	28516	9024

Table 5.4 Hourly path lengths left behind by specific F scale or stronger tornadoes computed as cumulative path lengths of the individual path length in Table 5.3.

Hour (CST)	F5	F4+	F3+	F2+	F1+	F0+
0000-0100	29	203	644	1535	2170	2318
0100-0200	0	112	591	1427	2069	2156
0200-0300	75	316	1058	1892	2523	2619
0300-0400	0	251	692	1386	1721	1763
0400-0500	0	80	357	1006	1427	1474
0500-0600	0	359	580	984	1321	1382
0600-0700	0	36	644	1102	1441	1500
0700-0800	58	210	442	920	1417	1482
0800-0900	86	277	481	1067	1402	1488
0900-1000	59	94	345	1012	1502	1613
1000-1100	82	441	708	1480	1936	2121
1100-1200	0	196	808	1469	2041	2240
1200-1300	78	346	871	2369	3334	3596
1300-1400	464	1014	2203	3683	5010	5548
1400-1500	489	1641	2825	5245	7322	8082
1500-1600	326	2407	4717	8330	10473	11344
1600-1700	205	2190	4996	9549	12437	13457
1700-1800	281	3056	6384	10654	12243	15482
1800-1900	137	2846	6044	10279	13152	14185
1900-2000	233	1140	3919	7116	9426	10119
2000-2100	79	1002	2645	5445	7232	7838
2100-2200	132	729	2094	3821	4962	5350
2200-2300	43	243	1439	2646	3568	3786
2300-2400	36	309	1056	2346	3155	3371
0000-2400	2888	19486	46524	86740	115256	124280

5.2 Bi-hourly Distribution Maps

Geographic distribution of tornadoes at two-hour (2hr) intervals are presented in the following twelve (12) pages (p71-82). The upper maps with blue symbols show the distribution of tornado occurrences in 70 years, 1916-1985, and the lower maps with red symbols, those of tornado path lengths for the same period.

Tornado activities in both occurrence and path length decrease from 0000 CST to 0600 CST, when they reach the diurnal minimum. The 0000-0200 CST tornadoes over the entire area east of the Rockies are the remnants of the previous day's activity on the 2200-2400 CST map. It is seen that the tornadoes in the upper Midwest disappear by 6 a.m.

After 0800 CST, tornadoes in the Gulf states increase, spreading quickly northward. By mid-afternoon, the activity areas cover the entire country. At the peak time, 1600-1800 CST, a broad area of intense activity extends from Texas to Iowa. Thereafter, the overall activity decreases toward the end of the day (2200-2400) as seen in the distributions depicted in Figs. 5.25 and 5.26. It should be noted that these last maps of the day continue to the first maps (0000-0200 CST) of the day on page 71.

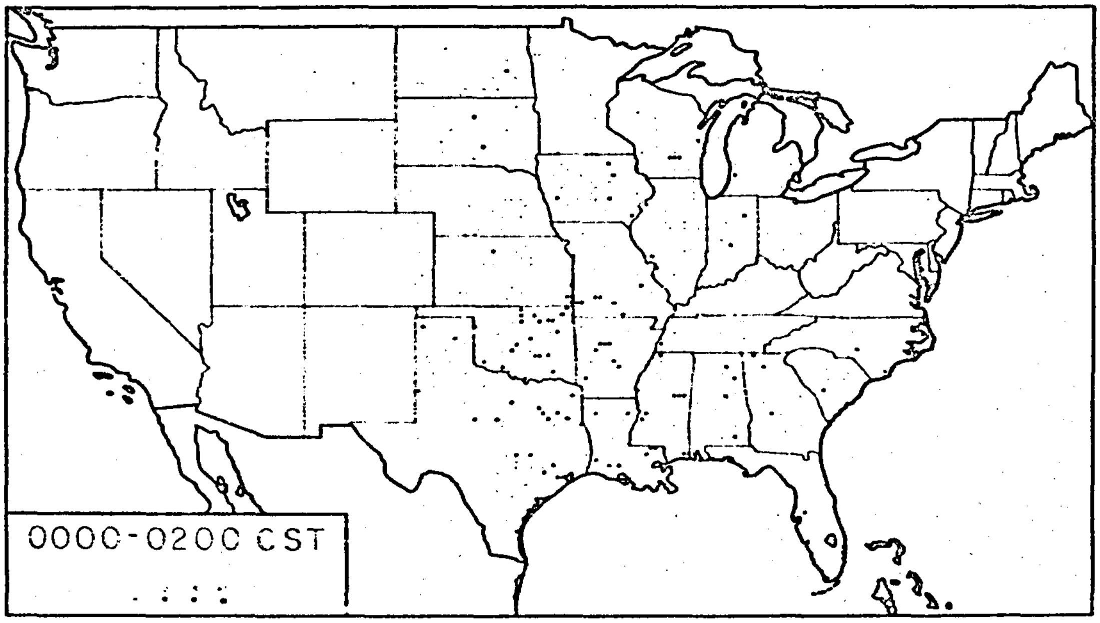


Fig. 5.3 Occurrences of tornadoes between 00 and 02 CST.

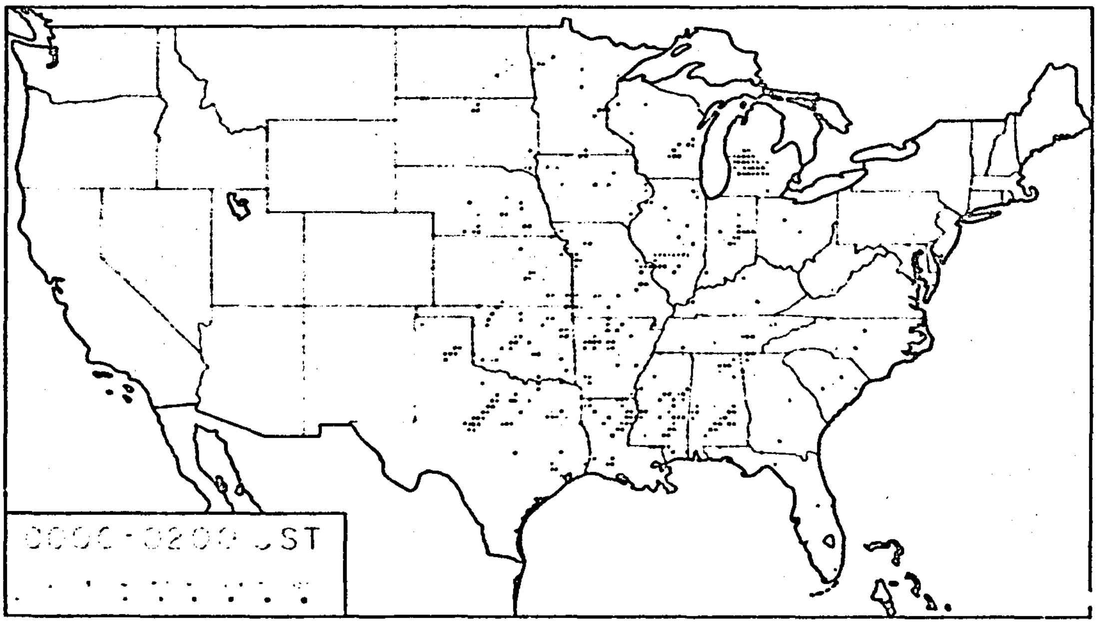


Fig. 5.4 Path lengths of tornadoes between 00 and 02 CST.

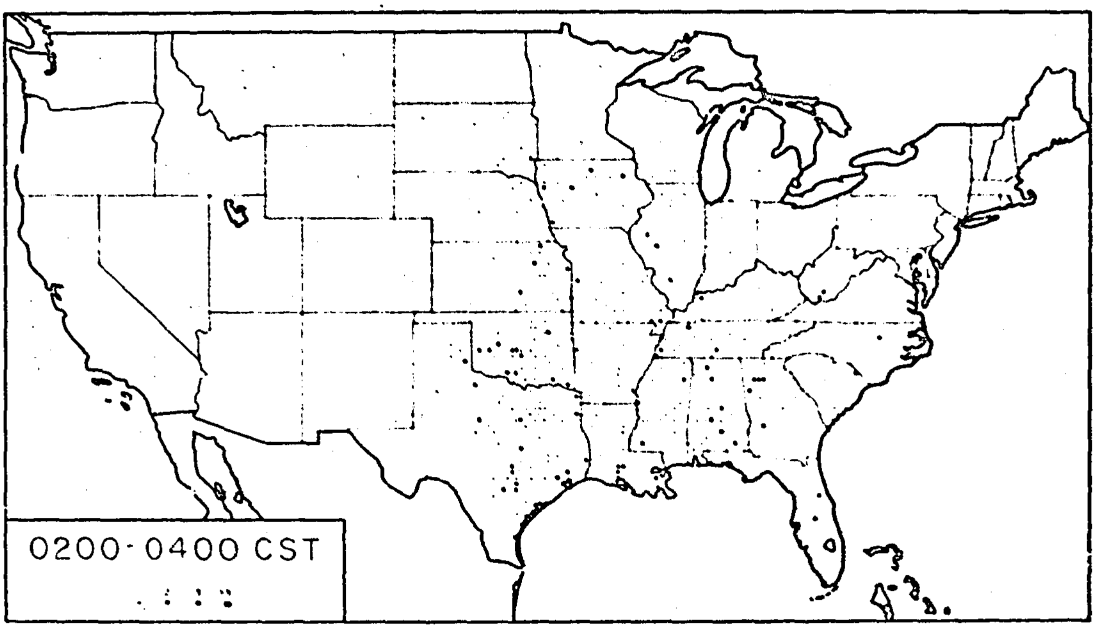


Fig. 5.5 Occurrences of tornadoes between 02 and 04 CST.

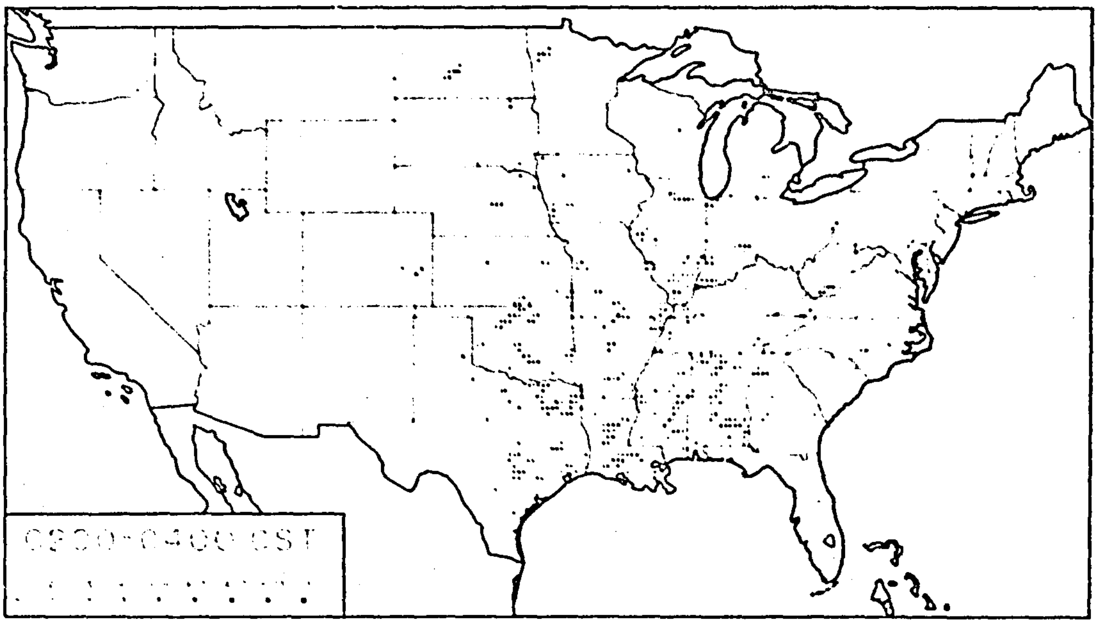


Fig. 5.6 Path lengths of tornadoes between 02 and 04 CST.

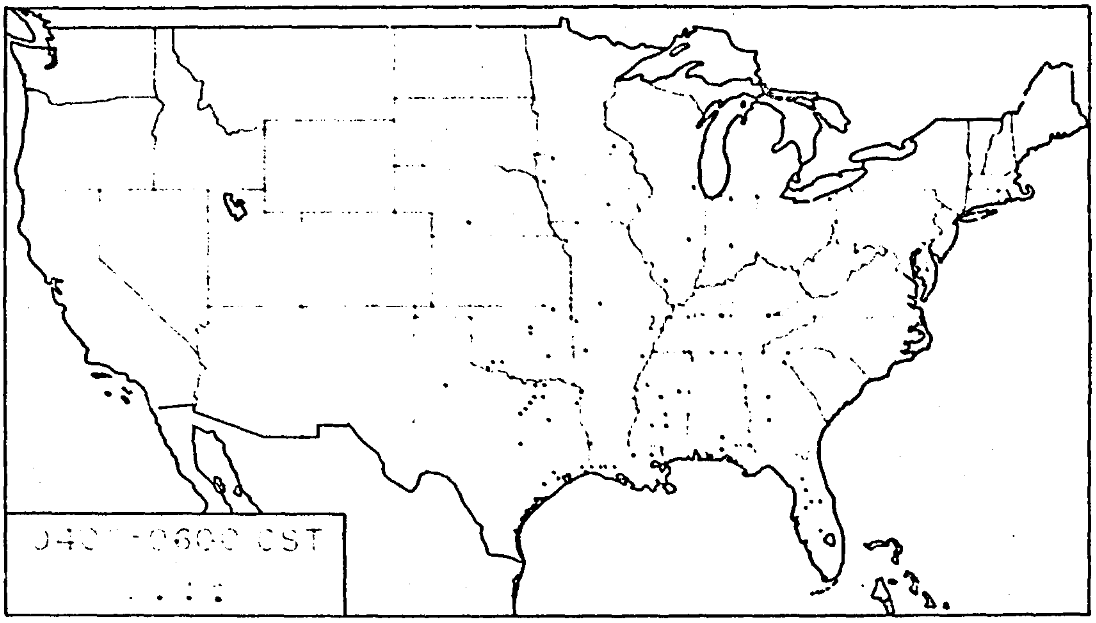


Fig. 5.7 Occurrences of tornadoes between 04 and 06 CST.

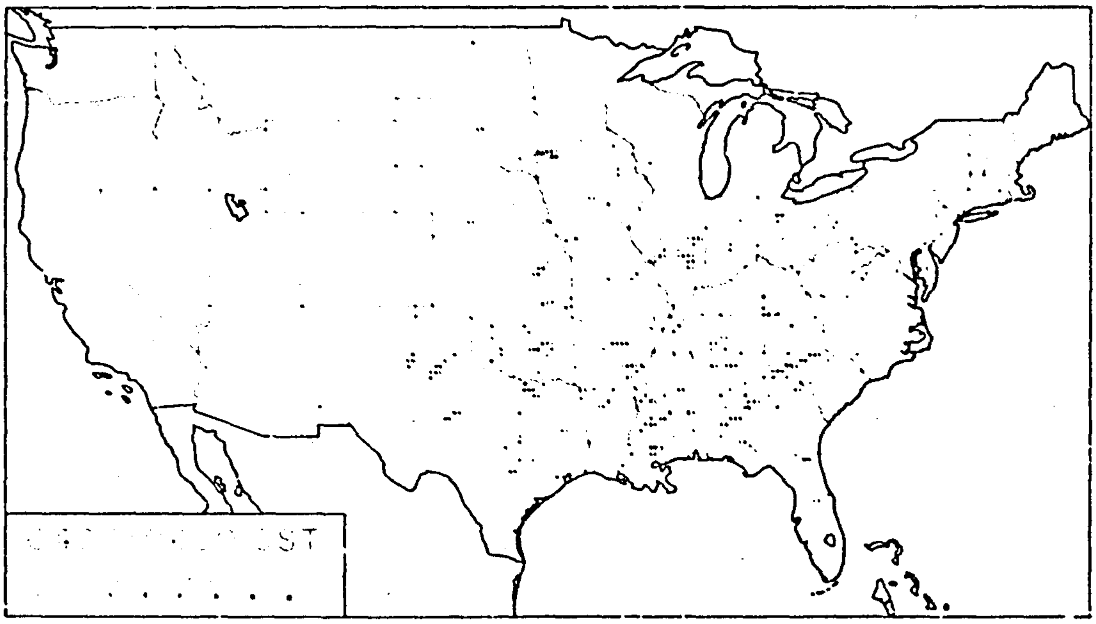


Fig. 5.8 Path lengths of tornadoes between 04 and 06 CST.

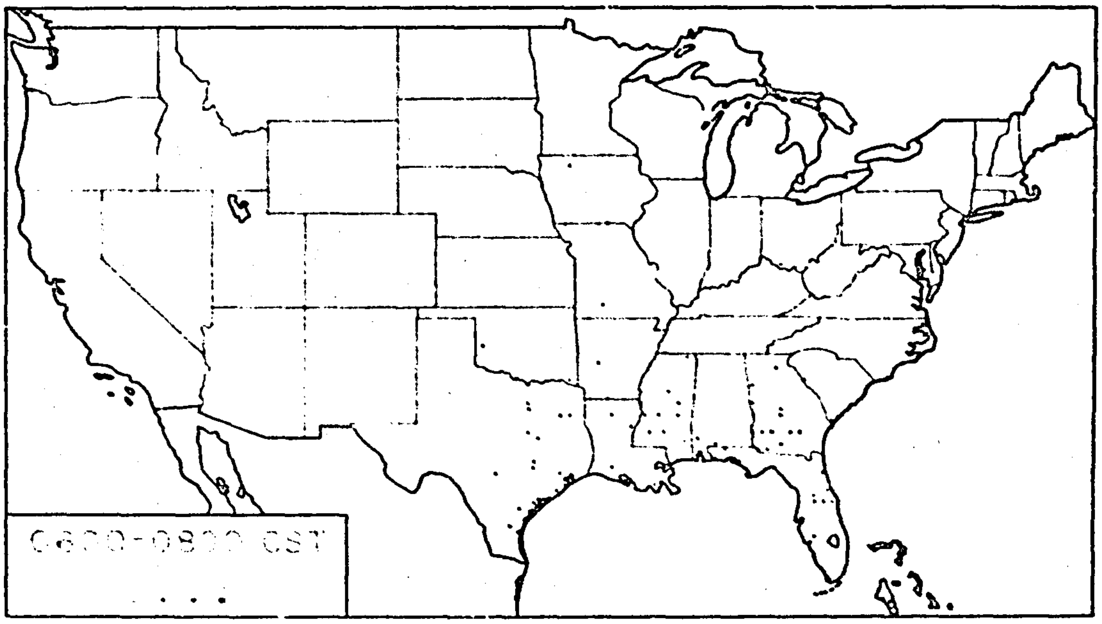


Fig. 5.9 Occurrences of tornadoes between 06 and 08 CST.

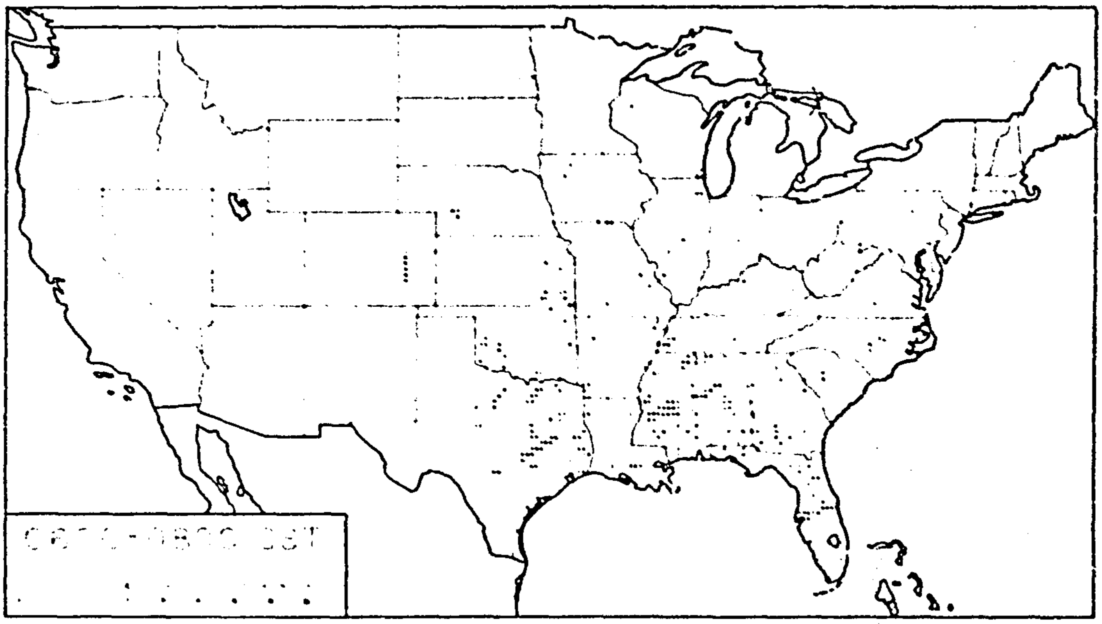


Fig. 5.10 Path lengths of tornadoes between 06 and 08 CST.

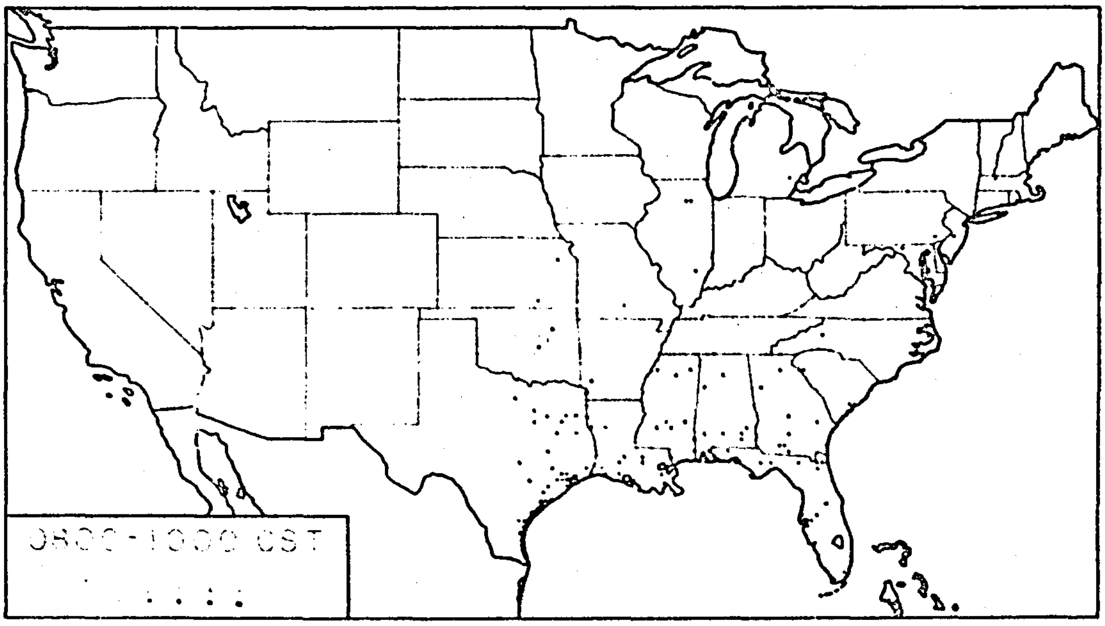


Fig. 5.11 Occurrences of tornadoes between 08 and 10 CST.

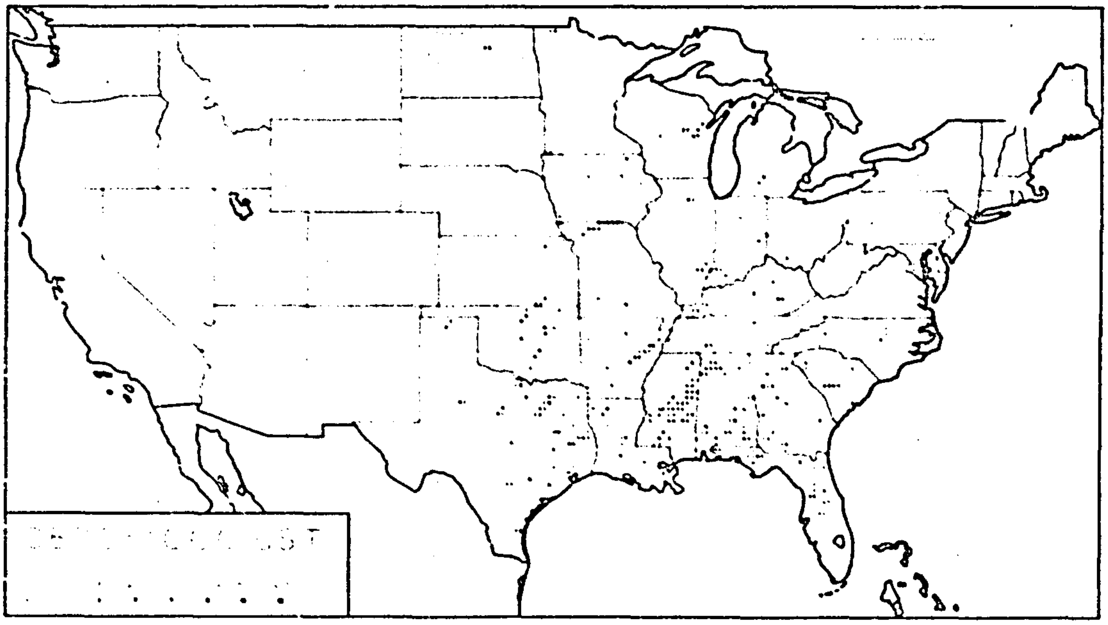


Fig. 5.12 Path lengths of tornadoes between 08 and 10 CST.

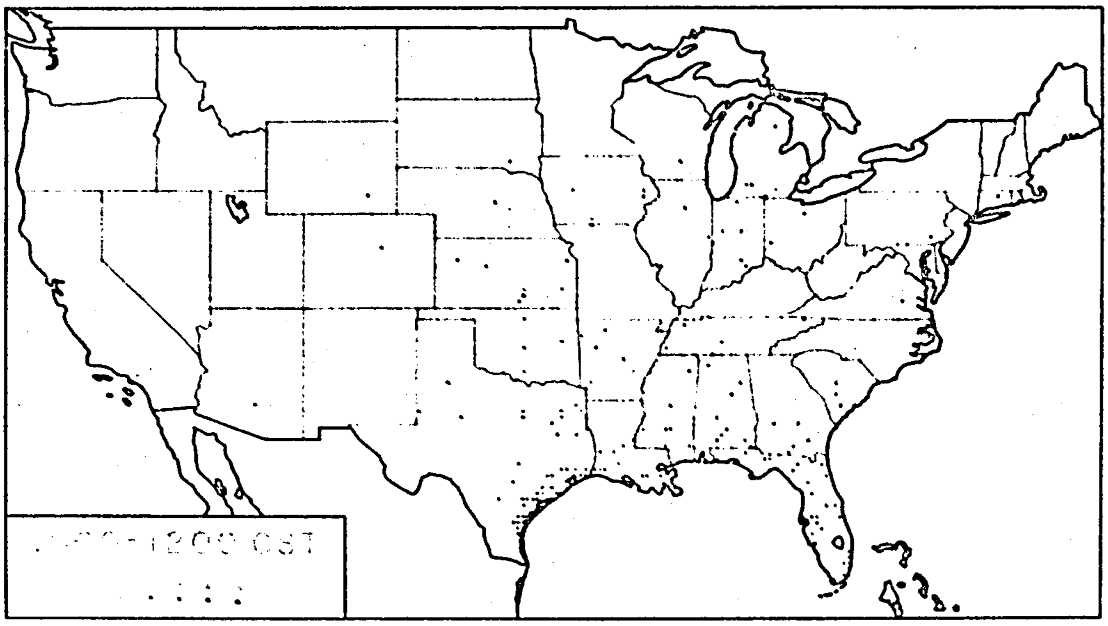


Fig. 5.13 Occurrences of tornadoes between 10 and 12 CST.

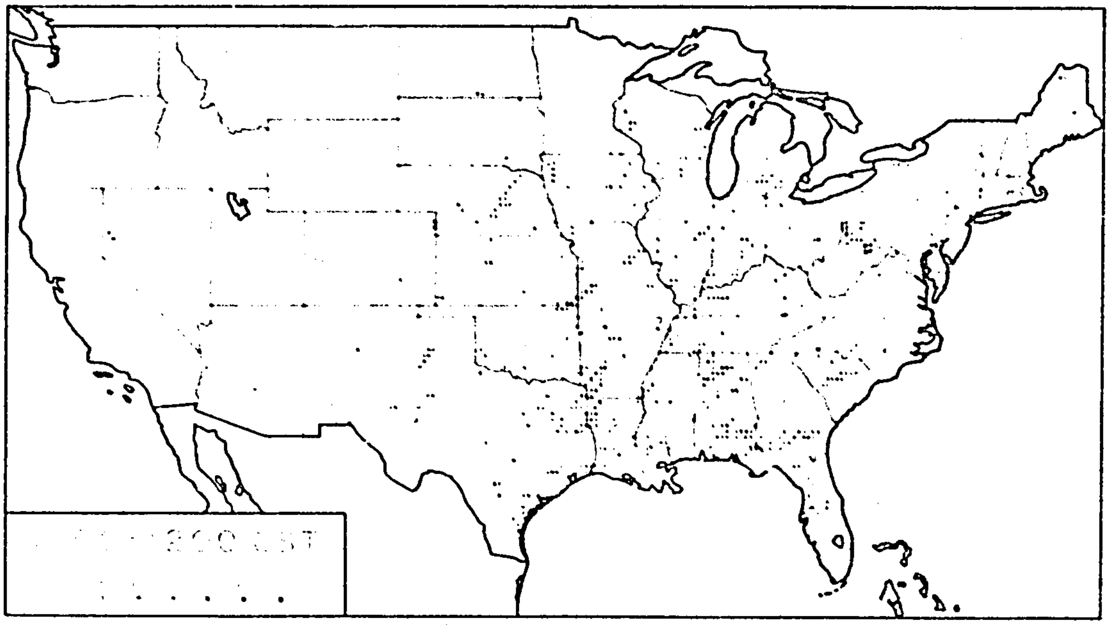


Fig. 5.14 Path lengths of tornadoes between 10 and 12 CST.

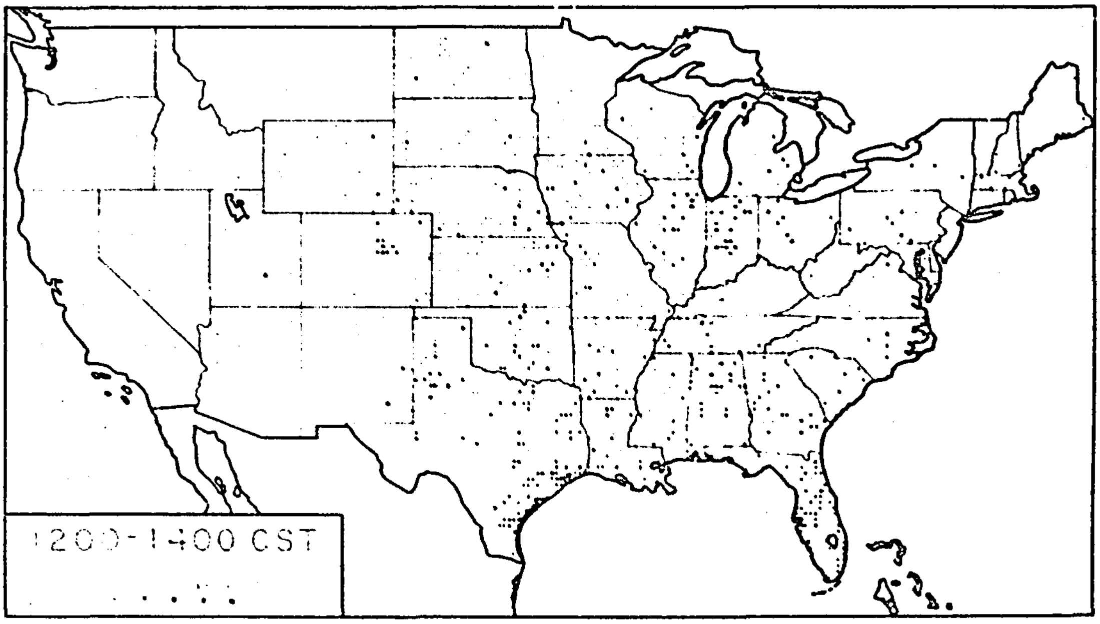


Fig. 5.15 Occurrences of tornadoes between 12 and 14 CST.

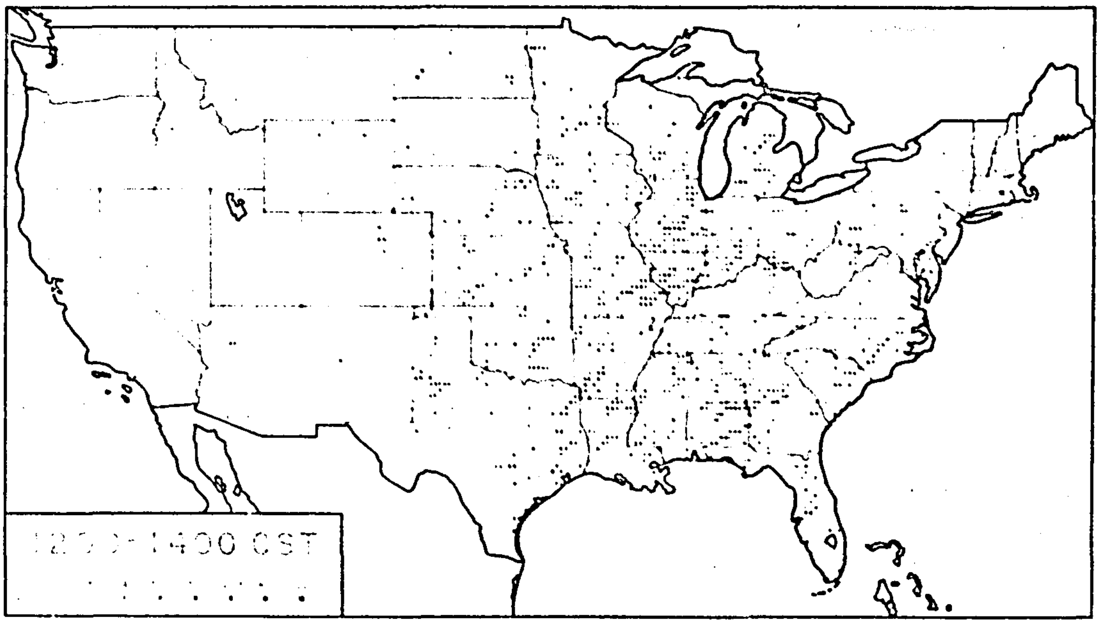


Fig. 5.16 Path lengths of tornadoes between 12 and 14 CST.

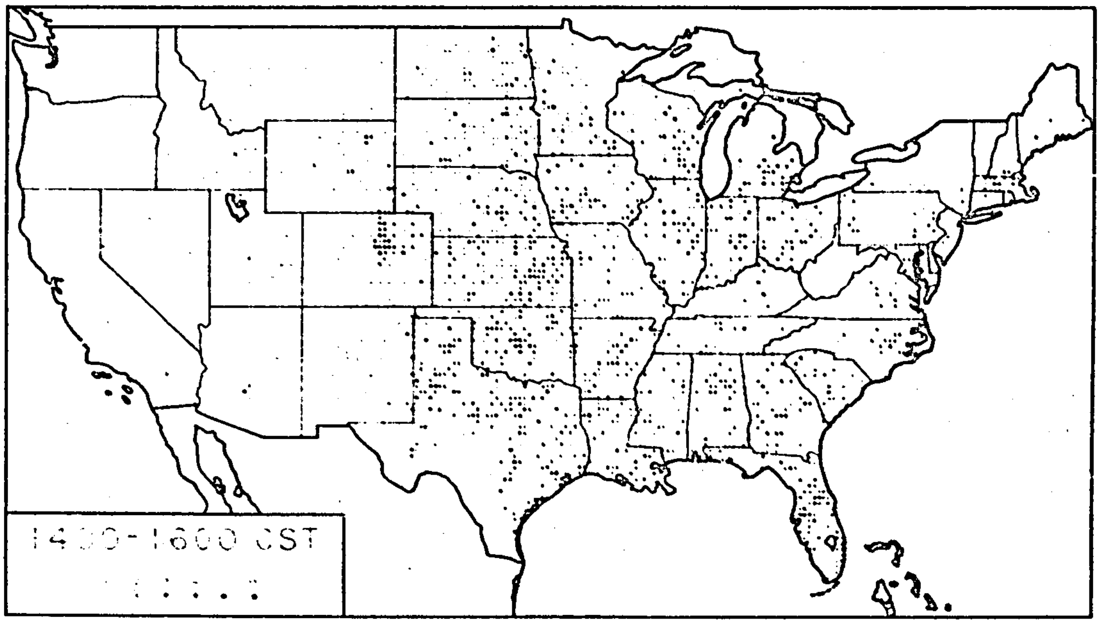


Fig. 5.17 Occurrences of tornadoes between 14 and 16 CST.

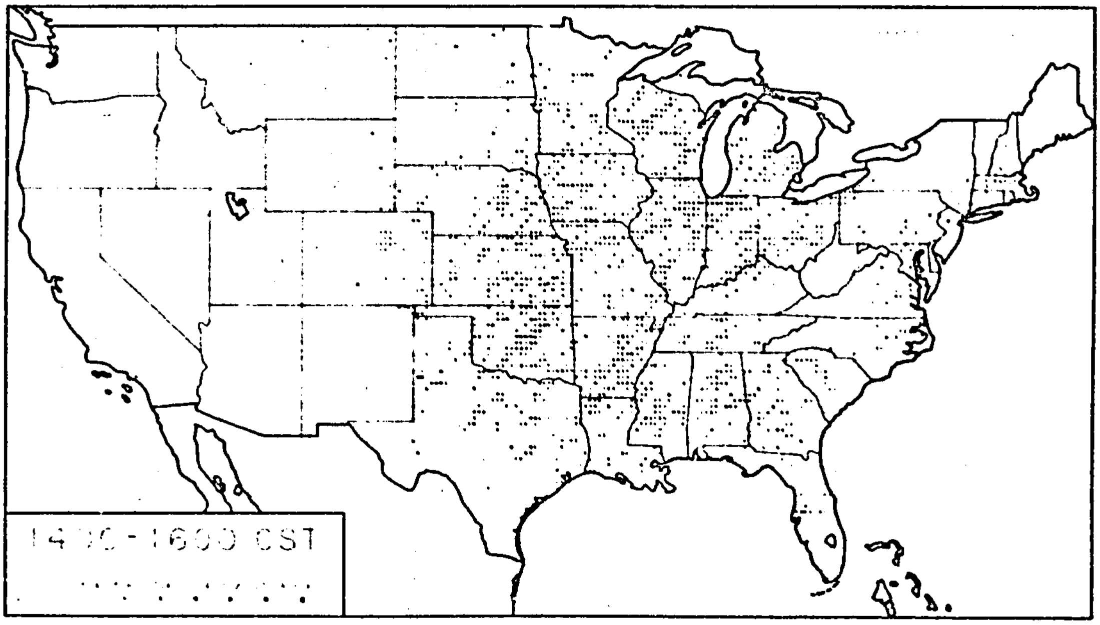


Fig. 5.18 Path lengths of tornadoes between 14 and 16 CST.

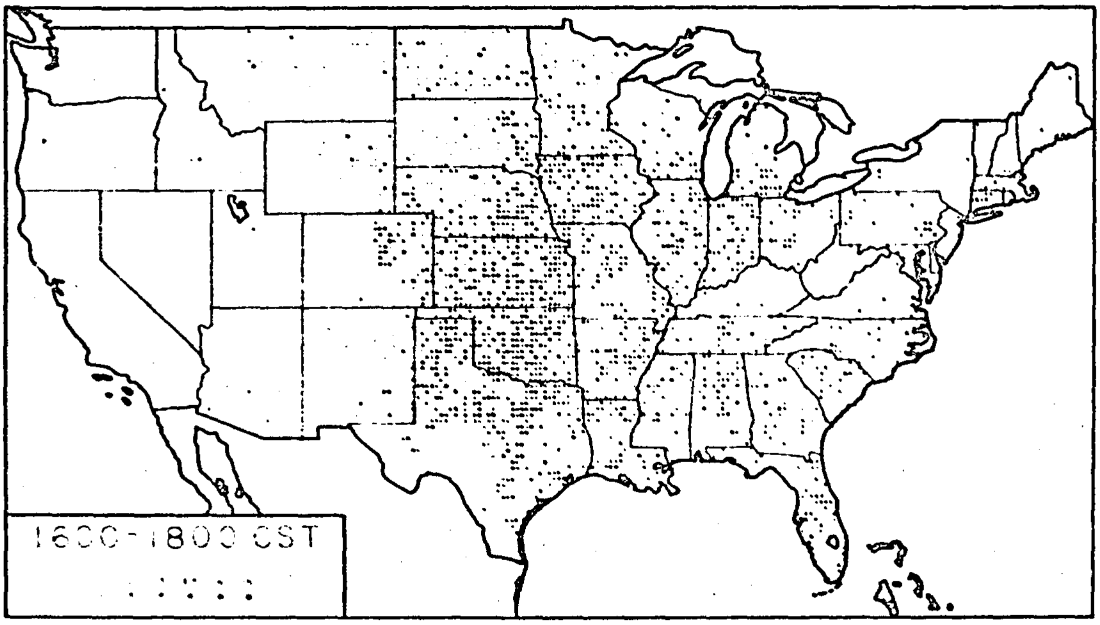


Fig. 5.19 Occurrences of tornadoes between 16 and 18 CST.

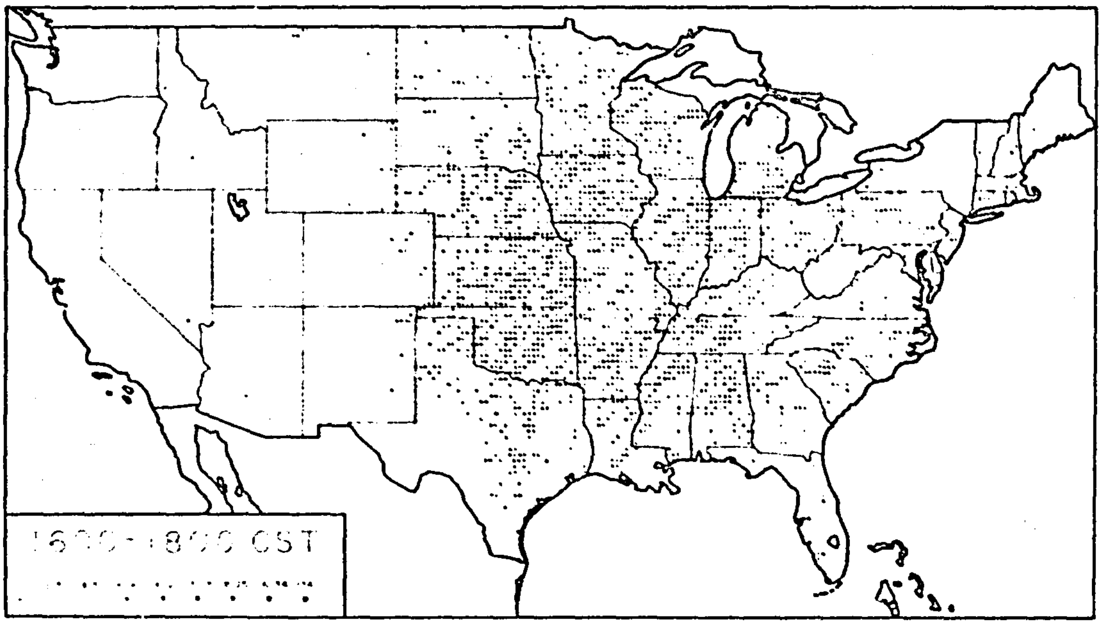


Fig. 5.20 Path lengths of tornadoes between 16 and 18 CST.

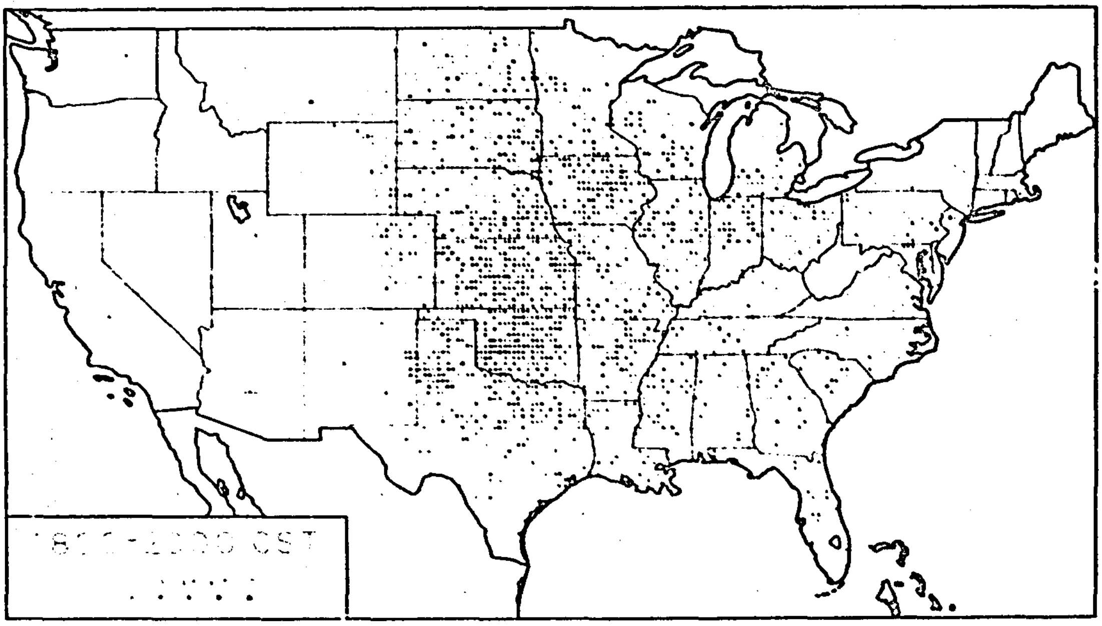


Fig. 5.21 Occurrences of tornadoes between 18 and 20 CST.

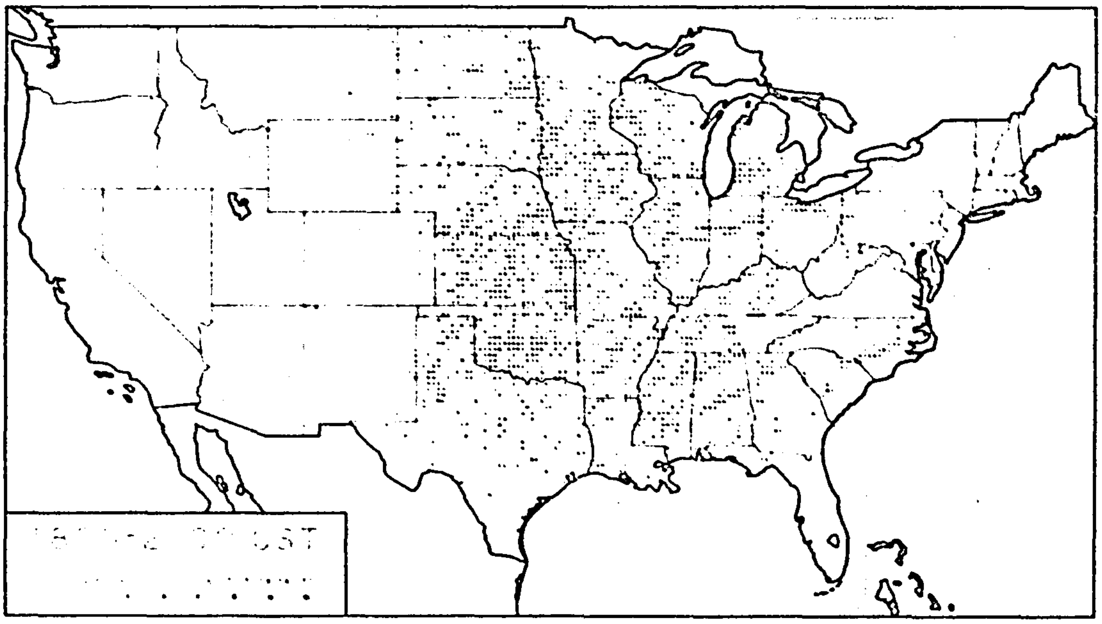


Fig. 5.22 Path lengths of tornadoes between 18 and 20 CST.

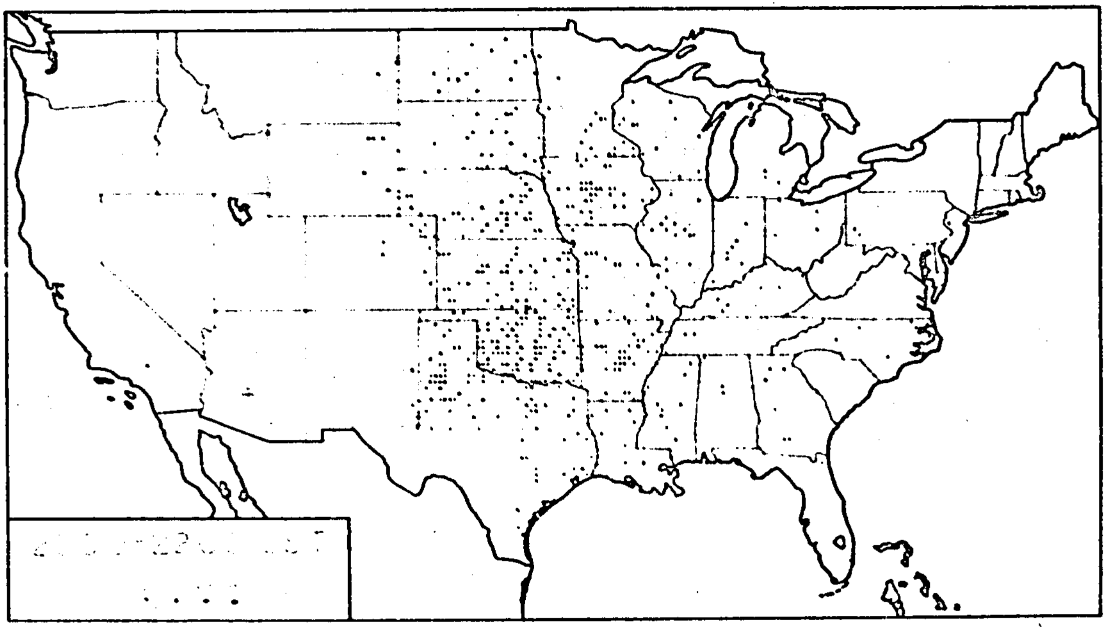


Fig. 5.23 Occurrences of tornadoes between 20 and 22 CST.

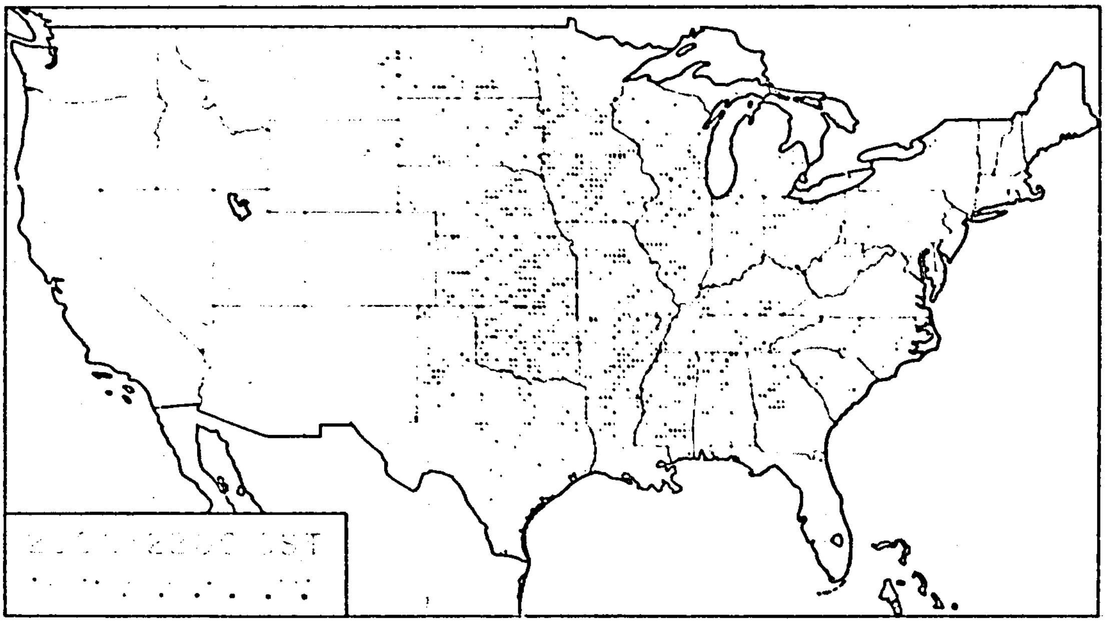


Fig. 5.24 Path lengths of tornadoes between 20 and 22 CST.

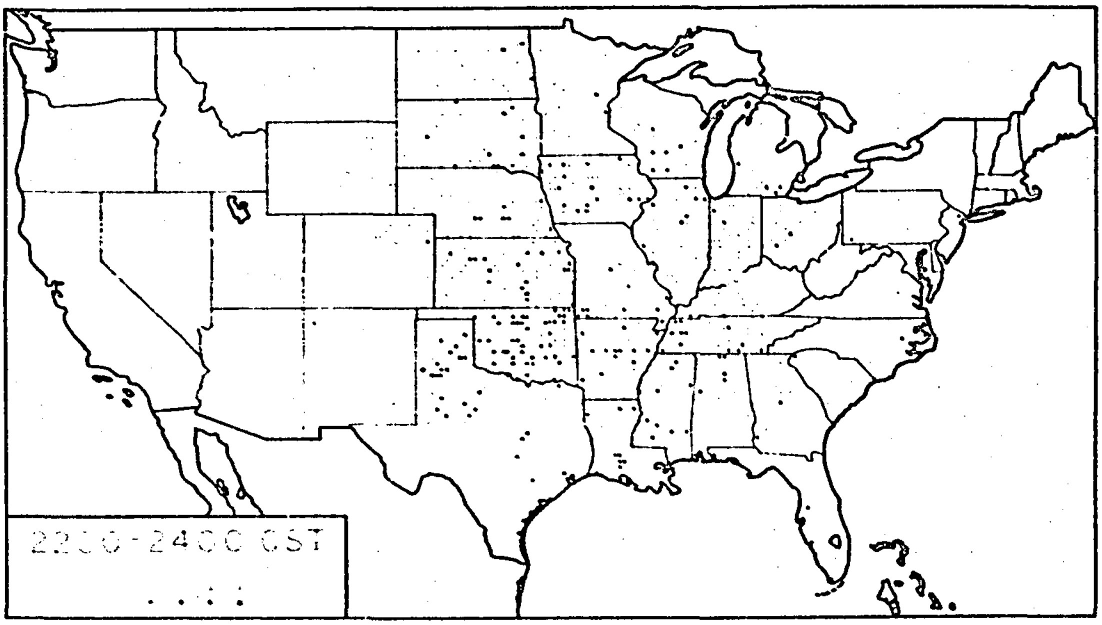


Fig. 5.25 Occurrences of tornadoes between 22 and 24 CST.

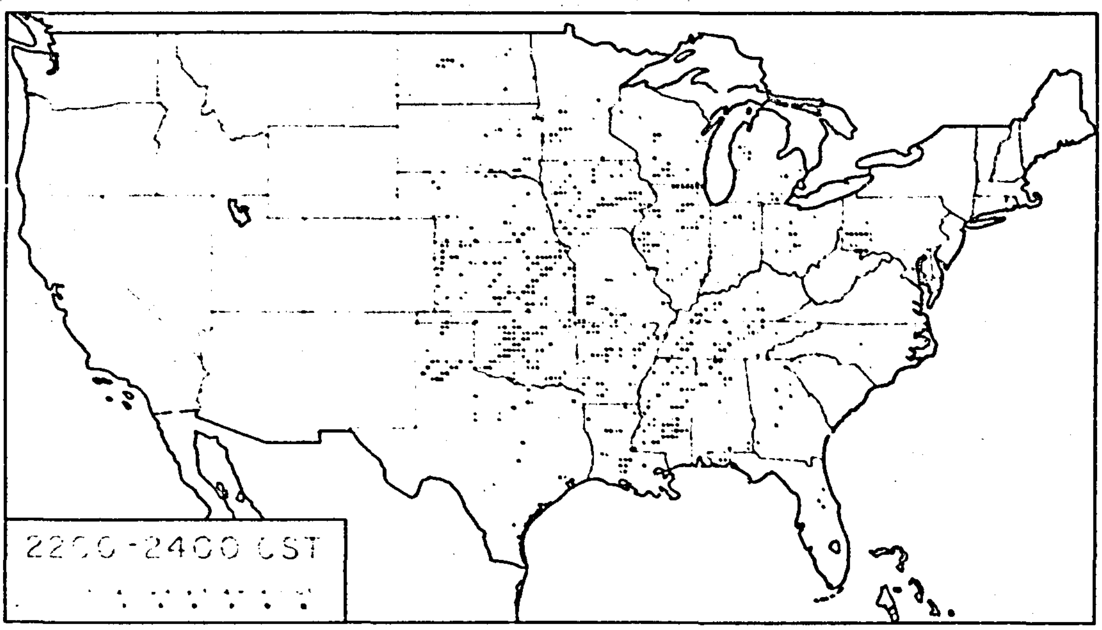


Fig. 5.26 Path lengths of tornadoes between 22 and 24 CST.

Chapter Six

Tornado Outbreaks

A "tornado day" is a day on which one or more tornadoes are confirmed. During the 70-year period, 1916-1985, there were 8,136 tornado days which is 31.8% of the total number of days in this period. A tornado day begins at 6 a.m. CST of the day.

6.1 Tornado Outbreaks

The number of tornado days by tornado occurrences in Table 6.1 reveals that the largest number of occurrences on a single day were 144. These tornadoes occurred on the first day of the April 3-4, 1974 superoutbreak listed in Table 6.2.

Figure 6.1 was made by ranking the daily tornado occurrences into "few occurrences" (1 to 4), "medium occurrences" (5 to 19), and "many occurrences" (20 to 144). Although the mimimum number of occurrences required to be called an outbreak has not been officially decided, a day with 20 or more occurrences may be called an "outbreak day".

The largest number of daily occurrences during the 70-year period, 1916-1985, was recorded on the first day of the April 3-4, 1974 outbreak. Because the outbreak was the largest in number of occurrences and the longest in combined path lengths, it was called the "superoutbreak".

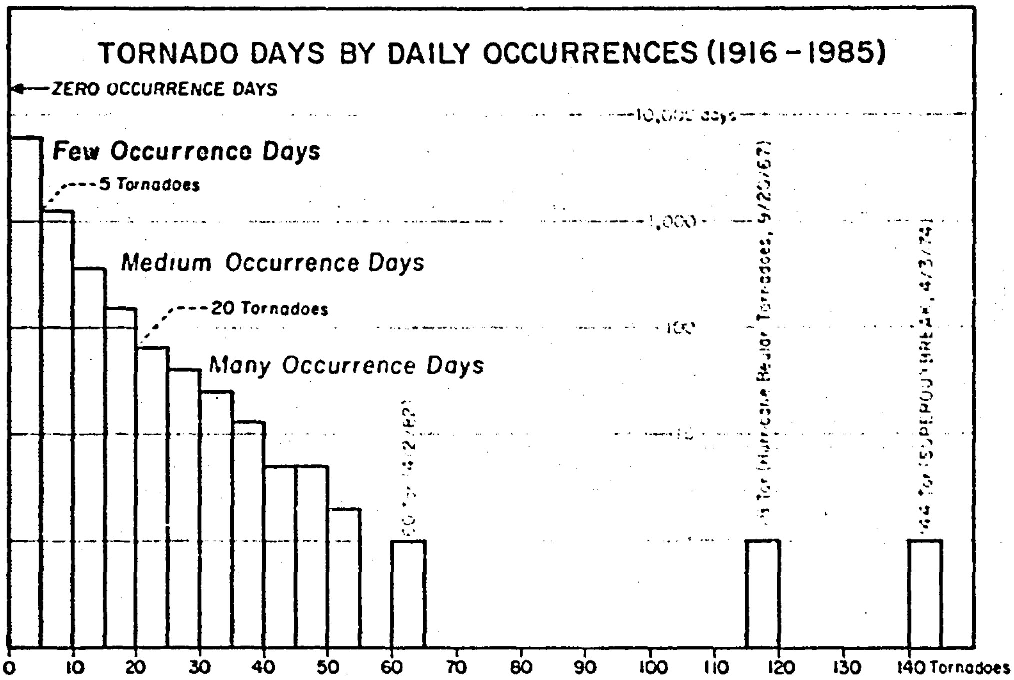


Fig. 6.1 Number of tornado days which decreases with daily occurrrences. There were 17,432 zero occurrence days (tornado-free days) which is 68.2% of the 25,568 days in 70 years. As the number of occurrences increase, the number of tornado days decreases very rapidly. The total number of tornado days with 20 or more occurrences is only 152, which ranks as the top 2% of the total tornado days. This is why a day with 20 or more occurrences may be called an "outbreak day".

Table 6.1 Number of tornado days in each month tabulated as a function of daily tornado occurrences. The number of tornado days in each month is: JAN 213 days (9.8%), FEB 275 (13.9%), MAR 614 (28.3%), APR 912 (43.4%), MAY 1268 (58.4%), JUN 1304 (62.1%), JUL 1152 (53.1%), AUG 915 (42.2%), SEP 622 (29.6%), OCT 353 (16.3%), NOV 289 (13.8%), and DEC 219 (10.1%). This result shows that tornado days in January are less than 10% and those in June exceed 60%.

Daily Occurrences	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0	1957	1703	1556	1188	902	796	1018	1255	1478	1817	1811	1951	17432
1-4	182	214	463	613	805	866	970	825	556	302	236	172	6204
5-9	16	43	93	165	264	294	152	73	55	35	37	29	1256
10-14	11	14	35	71	93	80	23	10	4	9	6	9	365
15-19	2	2	9	27	48	35	6	3	5	4	6	5	152
20-24	-	1	8	16	22	10	-	2	1	2	3	-	65
25-29	-	1	2	8	13	11	1	1	-	1	-	3	41
30-34	1	-	3	6	8	5	-	1	-	-	1	-	25
35-39	1	-	-	1	9	2	-	-	-	-	-	-	13
40-44	-	-	-	1	3	-	-	-	-	-	-	1	5
45-49	-	-	-	1	3	1	-	-	-	-	-	-	5
50-54	-	-	1	1	-	-	-	-	-	-	-	-	2
55-59	-	-	-	-	-	-	-	-	-	-	-	-	-
60-64	-	-	-	1	-	-	-	-	-	-	-	-	1
65-69	-	-	-	-	-	-	-	-	-	-	-	-	-
70-74	-	-	-	-	-	-	-	-	-	-	-	-	-
75-79	-	-	-	-	-	-	-	-	-	-	-	-	-
80-84	-	-	-	-	-	-	-	-	-	-	-	-	-
85-89	-	-	-	-	-	-	-	-	-	-	-	-	-
90-94	-	-	-	-	-	-	-	-	-	-	-	-	-
95-99	-	-	-	-	-	-	-	-	-	-	-	-	-
100-104	-	-	-	-	-	-	-	-	-	-	-	-	-
105-109	-	-	-	-	-	-	-	-	-	-	-	-	-
110-114	-	-	-	-	-	-	-	-	-	-	-	-	-
115-119	-	-	-	-	-	-	-	-	1	-	-	-	1
120-124	-	-	-	-	-	-	-	-	-	-	-	-	-
125-129	-	-	-	-	-	-	-	-	-	-	-	-	-
130-134	-	-	-	-	-	-	-	-	-	-	-	-	-
135-139	-	-	-	-	-	-	-	-	-	-	-	-	-
140-144	-	-	-	1	-	-	-	-	-	-	-	-	1
Total	2170	1978	2170	2100	2170	2100	2170	2170	2100	2170	2100	2170	25568

Table 6.2 A list of the top fifteen (15) tornado occurrences on a single day (6 a.m. to 6 a.m.). The first day of the superoutbreak tornadoes was number one, followed by the Hurricane Beulah day.

Rank	Occurrences	Date	Remarks
1.	144	04/03/74	Superoutbreak tornadoes of April 3-4, 1974. Tennessee, Kentucky, Indiana, Illinois, Ohio, Michigan, New York, Alabama, Georgia, North Carolina, Virginia, West Virginia, and Mississippi. 315 persons were killed and 5,484 were injured.
2.	118	09/20/67	Hurricane Beulah induced tornadoes. Mostly near the coast of Texas and within the Corpus Christi, San Antonio, and Houston triangle.
3.	60	04/02/82	Missouri, Oklahoma, Arkansas, Tennessee, and Illinois. 30 persons were killed and 383 were injured.
4.	52	04/21/67	Illinois, which included the Oak Lawn tornado immediately southwest of Chicago, Missouri, Iowa, and Michigan.
5.	52	03/20/76	Illinois, Indiana, Louisiana, and Mississippi.
6.	49	05/04/59	Central and northen Kansas, Oklakoma, Indiana, and Nebraska.
7.	48	04/11/65	Palm Sunday tornadoes. Ohio, Michigan, Wisconsin, Illinois, and Indiana. 258 persons were killed and 3,148 were injured.
8.	48	05/15/68	Missouri, Iowa, Arkansas, Indiana, and Minnesota.
9.	46	05/25/65	Kansas, Nebraska, Oklahoma, and Iowa.
10.	45	06/07/84	Upper Midwest outbreak. Iowa, Wisconsin, Minnesota, and Missouri.
11.	42	05/20/80	South Dakota, Iowa, Nebraska, and Kansas.
12.	42	04/29/84	Kansas, Missouri, and Illinois.
13.	41	05/24/57	Oklahoma, Texas, and Kansas.
14.	40	05/20/57	Oklahoma, Kansas, and Nebraska.
15.	40	12/14/71	Mostly in Texas, with a few in Missouri, Oklahoma, and Kentucky.

6.2 Tornado Days by Daily Path Length

Based on the path length of each tornado as stored in the University of Chicago Tornado Tape, the total path length on each tornado day was computed. Table 6.3 presents the number of days in each month on which various daily path lengths were left behind by daily tornadoes.

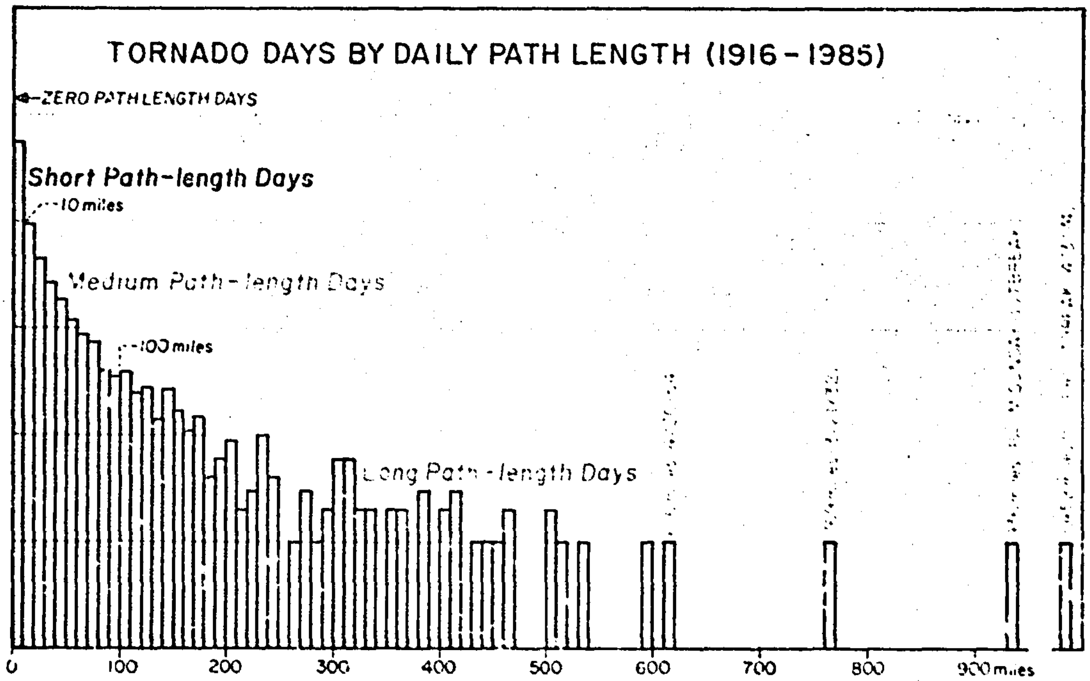


Fig. 6.2 In producing this diagram, path-length days were ranked, based on the total path length on each tornado day. Days with 1 to 9 miles are called "short path-length days"; 10 to 99 miles, "medium path-length days"; and 100 to the maximum, 2,452 miles, "long path-length days".

Table 6.3 Number of tornado days during the 70-year period tabulated by month and by path-length ranges. The maximum path length day was the first day of the superoutbreak tornadoes in 1974.

Daily Path Lengths	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0	1957	1703	1556	1188	902	796	1018	1255	1478	1817	1811	1951	17432
1-9	150	183	372	503	742	816	933	782	526	271	200	136	5614
10-19	30	38	82	114	182	195	123	72	40	37	33	27	973
20-29	10	12	40	72	90	103	36	27	25	19	14	14	462
30-39	7	5	17	36	68	63	18	17	9	5	10	14	269
40-49	4	10	20	37	38	34	18	2	6	6	8	3	186
50-59	3	3	17	23	26	23	13	3	3	3	4	3	124
60-69	2	7	8	21	13	19	4	2	2	2	3	6	89
70-79	-	2	11	20	13	12	3	5	3	3	3	2	77
80-89	-	2	4	11	14	4	1	1	-	1	3	-	41
90-99	-	2	4	5	8	9	1	1	1	1	2	2	36
100-109	2	2	4	8	13	6	1	1	1	1	-	1	40
110-119	1	1	2	4	9	3	-	1	-	2	1	1	25
120-129	-	2	6	6	7	1	-	1	2	1	2	1	29
130-139	-	2	-	4	4	3	-	-	-	-	-	1	14
140-149	1	1	2	8	6	3	-	-	1	-	2	3	27
150-159	1	-	3	6	3	3	-	-	1	-	-	-	17
160-169	-	-	2	5	2	1	-	-	1	-	-	-	11
170-179	1	-	3	5	3	-	1	-	-	-	1	1	15
180-189	-	-	-	1	3	-	-	-	-	-	-	-	4
190-199	-	1	1	-	1	-	-	-	-	-	1	2	6
200-209	-	-	3	1	2	1	-	-	1	-	1	-	9
210-219	-	-	1	-	-	-	-	-	-	-	-	1	2
220-229	-	-	-	-	1	1	-	-	-	-	1	-	3
230-239	-	-	2	5	3	-	-	-	-	-	-	-	10
240-249	-	-	1	1	2	-	-	-	-	-	-	-	4
250-259	-	-	-	-	-	-	-	-	-	-	-	-	-
260-269	-	-	-	1	-	-	-	-	-	-	-	-	1
270-279	-	-	-	3	-	-	-	-	-	-	-	-	3
280-289	-	-	-	1	-	-	-	-	-	-	-	-	1
290-299	-	-	1	-	1	-	-	-	-	-	-	-	2
300-309	1	-	-	3	2	-	-	-	-	-	-	-	6
310-319	-	-	1	1	2	1	-	-	-	-	-	1	6
320-329	-	-	2	-	-	-	-	-	-	-	-	-	2
330-339	-	1	-	-	1	-	-	-	-	-	-	-	2
340-349	-	-	-	-	-	-	-	-	-	-	-	-	-
350-359	-	-	-	-	2	-	-	-	-	-	-	-	2
360-369	-	-	-	-	2	-	-	-	-	-	-	-	2
370-379	-	-	-	-	-	-	-	-	-	-	-	-	-
380-389	-	-	-	2	-	-	-	-	-	1	-	-	3
390-399	-	-	-	-	-	-	-	-	-	-	-	-	-
400-409	-	-	-	-	1	1	-	-	-	-	-	-	2
410-419	-	1	1	1	-	-	-	-	-	-	-	-	3
420-429	-	-	-	-	-	-	-	-	-	-	-	-	-
430-439	-	-	-	-	-	1	-	-	-	-	-	-	1
440-449	-	-	-	1	-	-	-	-	-	-	-	-	1
450-459	-	-	1	-	-	-	-	-	-	-	-	-	1
460-469	-	-	-	-	2	-	-	-	-	-	-	-	2
470-499	-	-	-	-	-	-	-	-	-	-	-	-	-
500-509	-	-	1	-	1	-	-	-	-	-	-	-	2
510-519	-	-	-	-	1	-	-	-	-	-	-	-	1
530-539	-	-	1	-	-	-	-	-	-	-	-	-	1
590-599	-	-	-	-	-	1	-	-	-	-	-	-	1
610-619	-	-	-	1	-	-	-	-	-	-	-	-	1
760-769	-	-	1	-	-	-	-	-	-	-	-	-	1
930-939	-	-	-	1	-	-	-	-	-	-	-	-	1
2450-2459	-	-	-	1	-	-	-	-	-	-	-	-	1
Total	2170	1978	2170	2100	2170	2100	2170	2170	2100	2170	2100	2170	25568

■ Path length in miles

Table 6.4 A list of the top ten (10) tornado path lengths on a single day (6 a.m. to 6 a.m.). The first day of the superoutbreak tornadoes was number one, followed by the Palm Sunday tornadoes.

Rank	Path Lengths	Date	Remarks
1.	2452	04/03/74	Superoutbreak tornadoes of April 3-4, 1974. Tennessee, Kentucky, Indiana, Illinois, Ohio, Michigan, New York, Alabama, Georgia, North Carolina, Virginia, West Virginia, and Mississippi. 315 persons were killed and 5,484 were injured.
2.	936	04/11/65	Palm Sunday tornadoes. Ohio, Michigan, Wisconsin, Illinois, and Indiana. 258 persons were killed and 3,148 were injured.
3.	769	03/21/32	Mostly in Alabama and Georgia, with a few in Mississippi and Illinois.
4.	616	04/30/54	Mostly in Texas, Kansas, and Iowa, with a few in Kentucky and Missouri.
5.	594	06/07/84	Upper Midwest outbreak. Iowa, Wisconsin, Minnesota, and Missouri.
6.	539	03/30/38	Illinois, Arkansas, and Missouri.
7.	510	05/31/85	United States-Canada tornadoes. Ohio and Pennsylvania.
8.	509	03/16/42	Tennessee, Kentucky, Mississippi, Illinois, and Indiana.
9.	502	05/08/65	Mostly in Nebraska and South Dakota, with a few in Kansas and Oklahoma.
10.	469	05/05/60	Mostly in Arkansas, with a few in Texas and Iowa.

*Path length in miles

6.3 Maps by Daily Occurrence and Path Length

The following six maps denote the distribution of tornadoes on days with 1-4 tornadoes a day, 5-19 a day, and 20 or more a day. Presented thereafter are grid-print maps of tornadoes on tornado days with 1 to 9 miles in path length a day, 10 to 99 miles a day, and 100 miles or more a day.

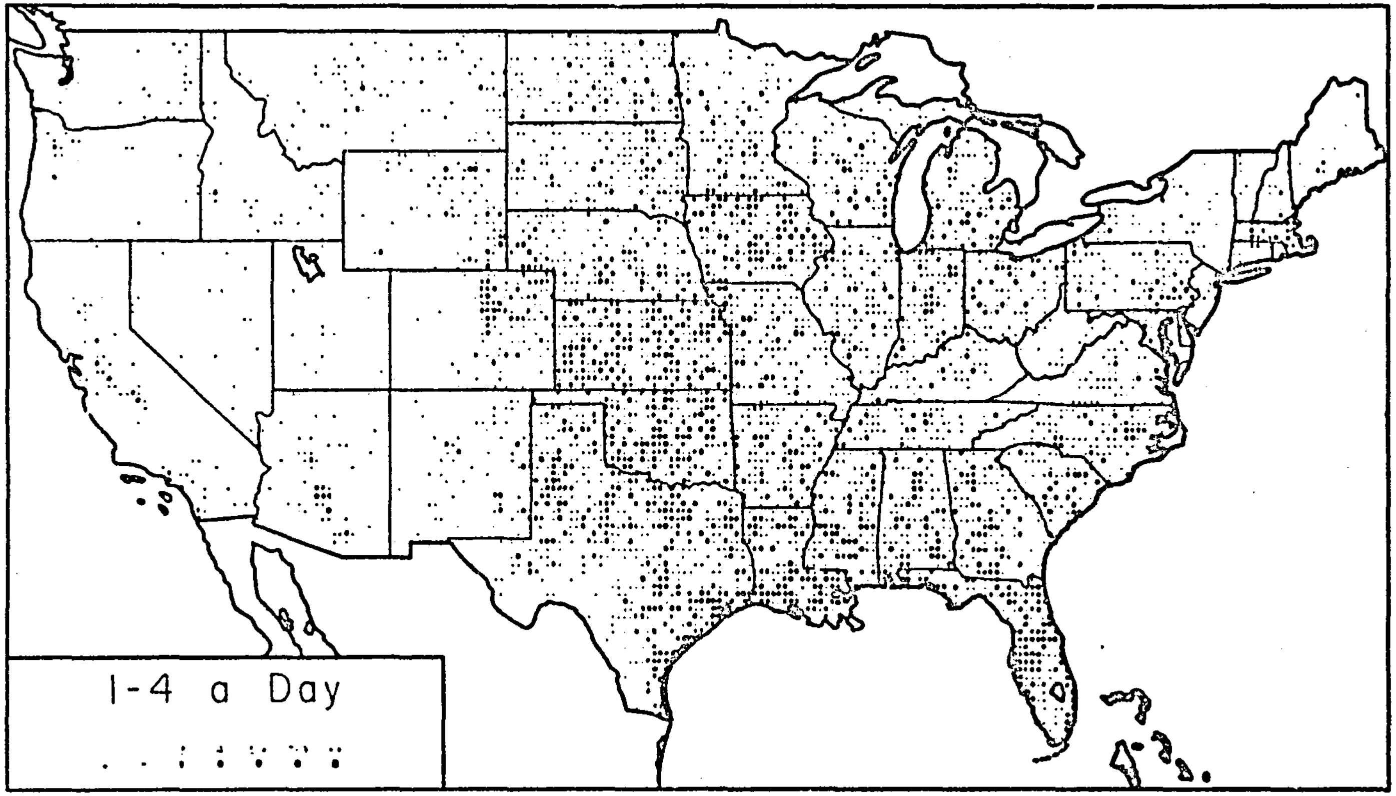


Fig. 6.3 Distribution of tornado occurrences on tornado days with 1 to 4 occurrences per day (few occurrence days). It is unlikely that tornadoes on these "few occurrence days" are spawned by organized storm systems.

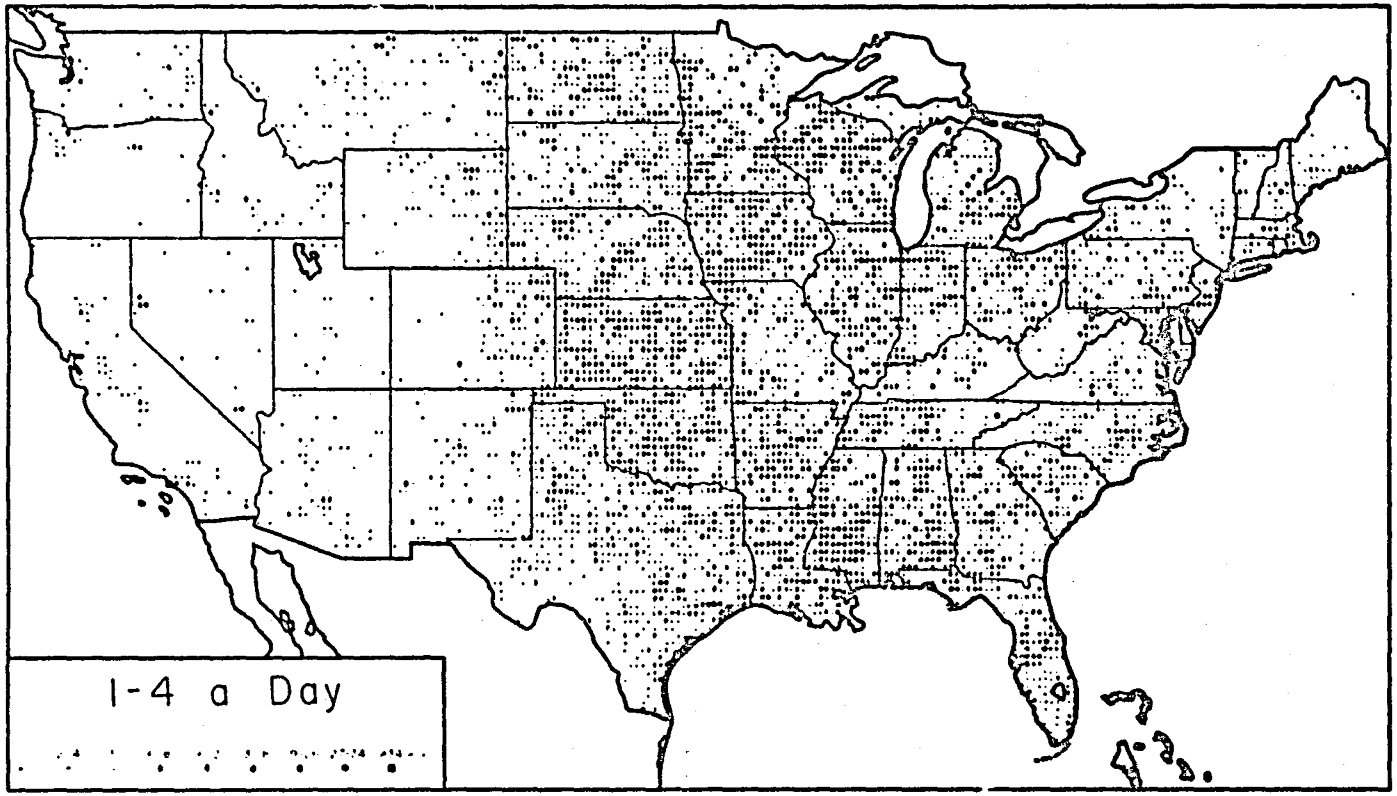


Fig. 6.4 Distribution of tornado path lengths on tornado days with 1 to 4 occurrences per day (few occurrence days).

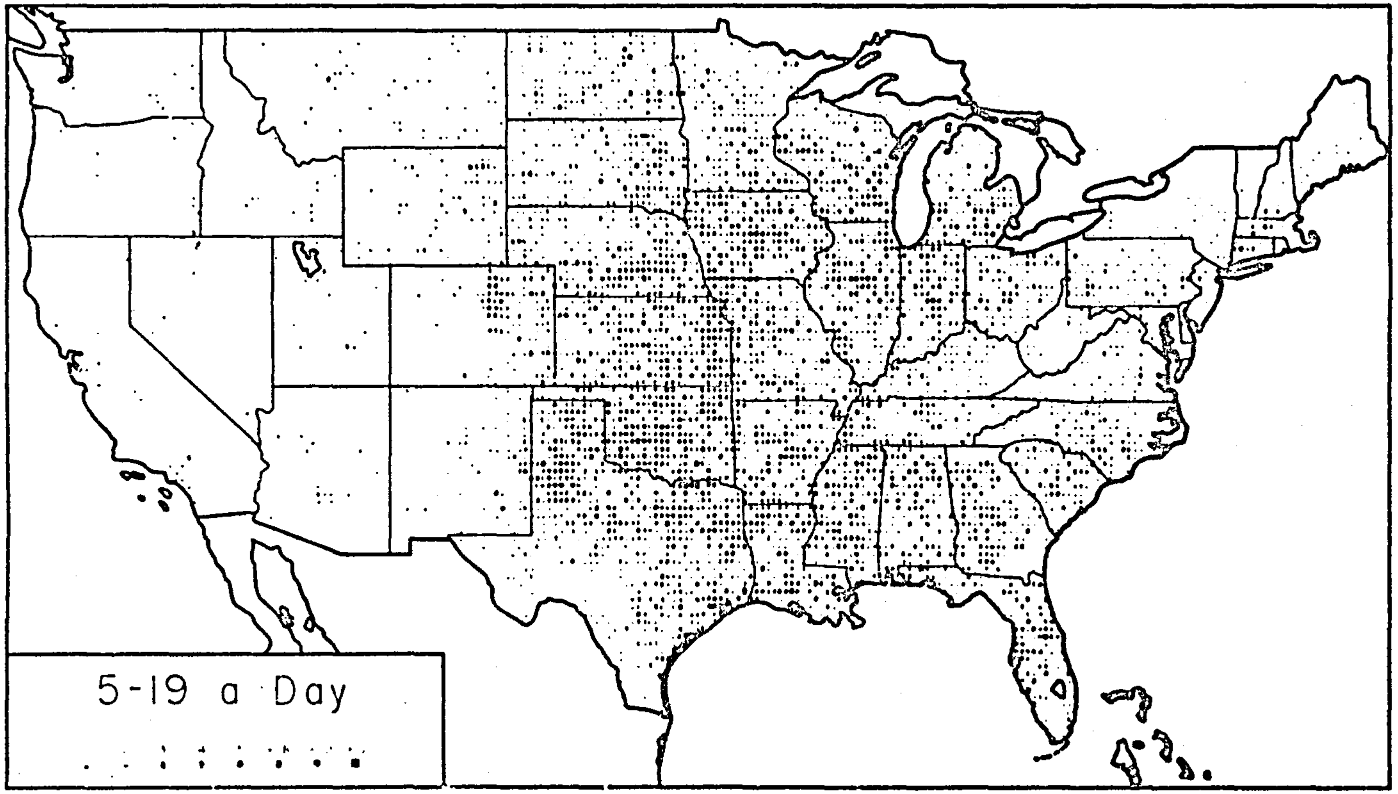


Fig. 6.5 Distribution of tornado occurrences on tornado days with 5 to 19 occurrences per day (medium occurrence days).

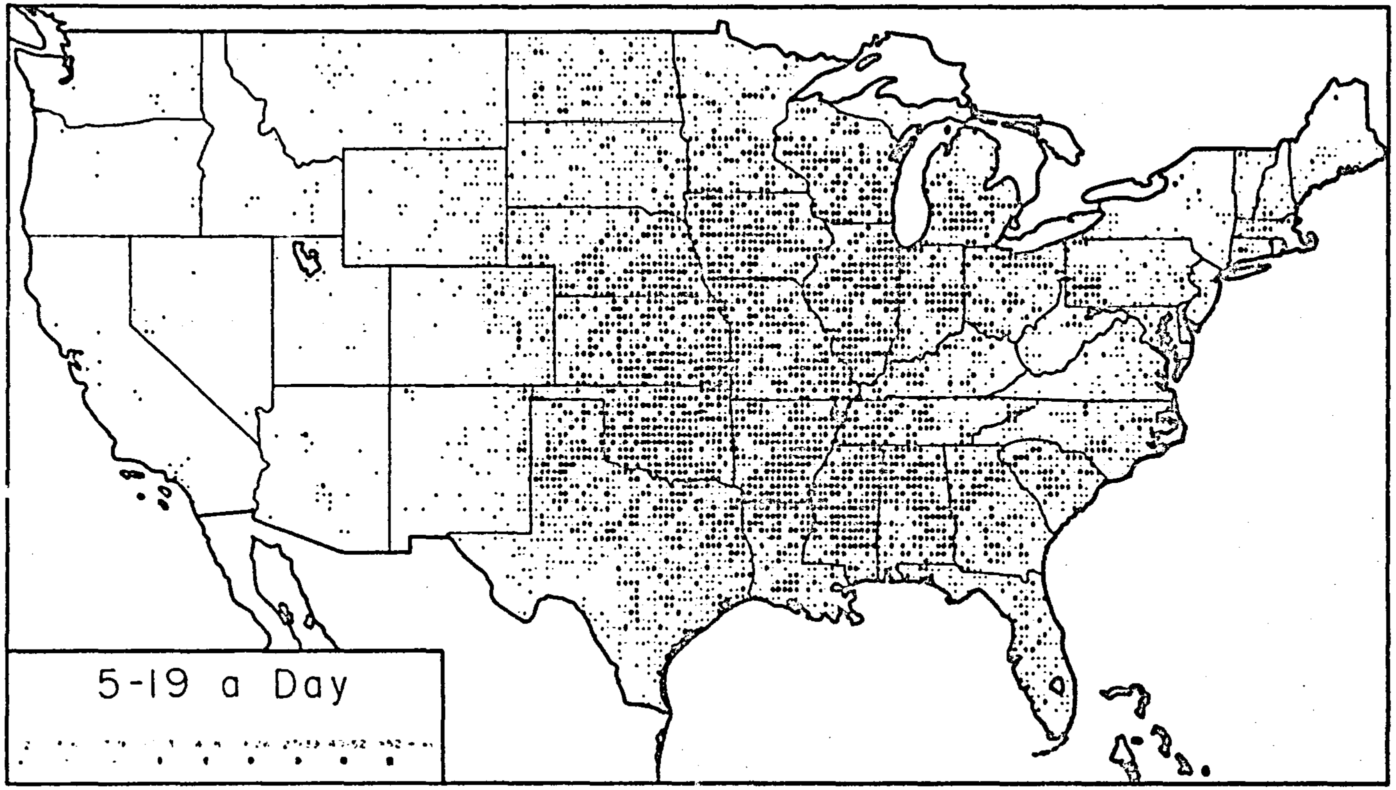


Fig. 6.6 Distribution of tornado path lengths on tornado days with 5 to 19 occurrences per day (medium occurrence days).

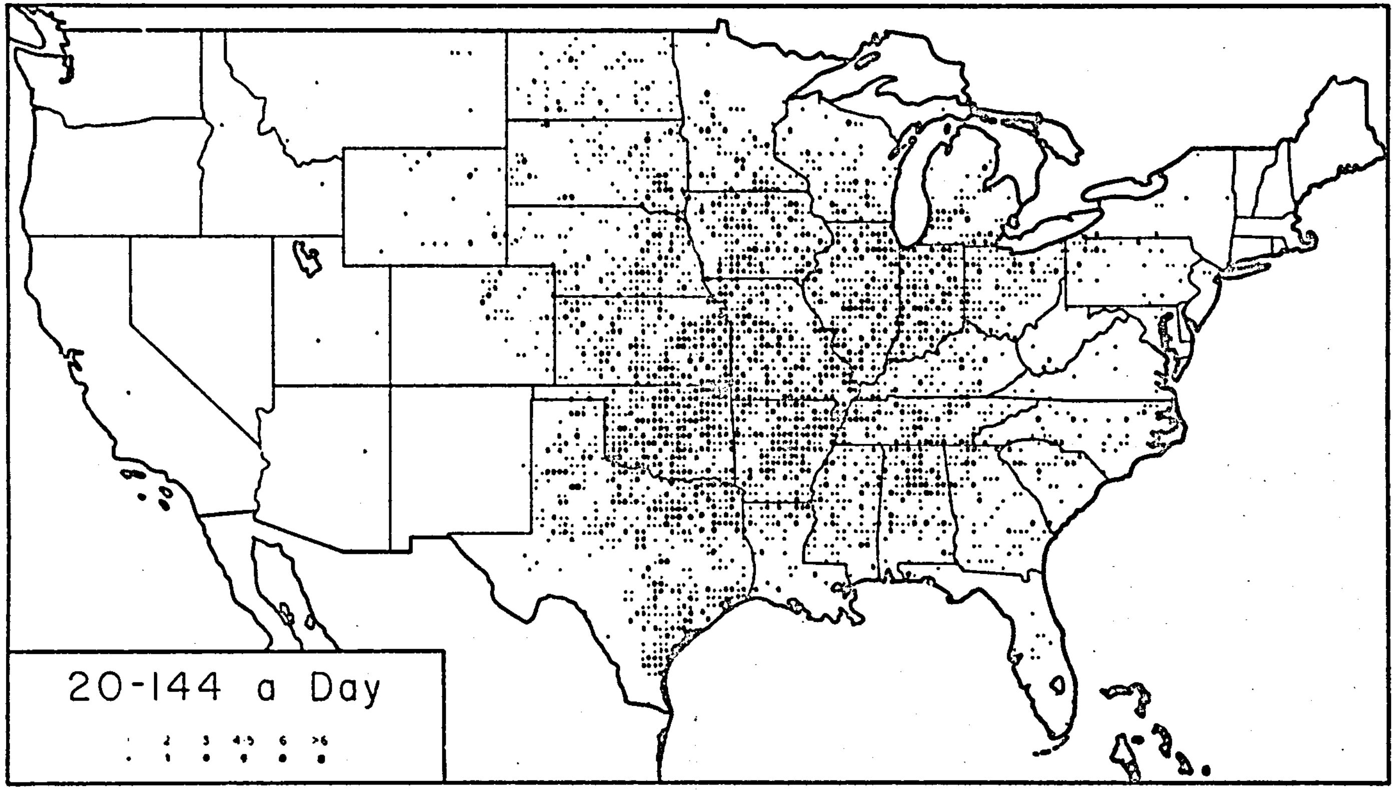


Fig. 6.7 Distribution of tornado occurrences on tornado days with 20 or more occurrences per day (outbreak days or many occurrence days).

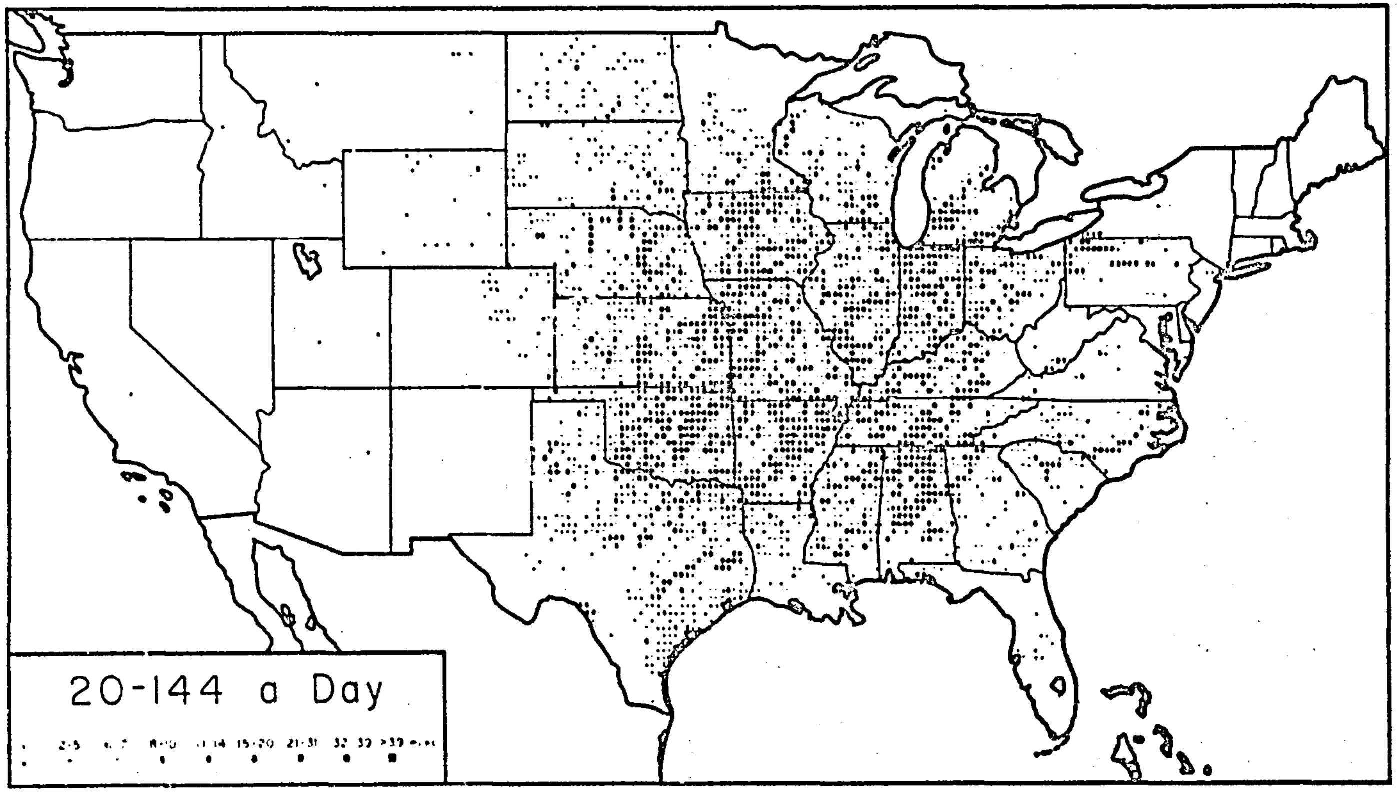


Fig. 6.8 Distribution of tornado path lengths on tornado days with 20 or more occurrences per day (outbreak days or many occurrence days).

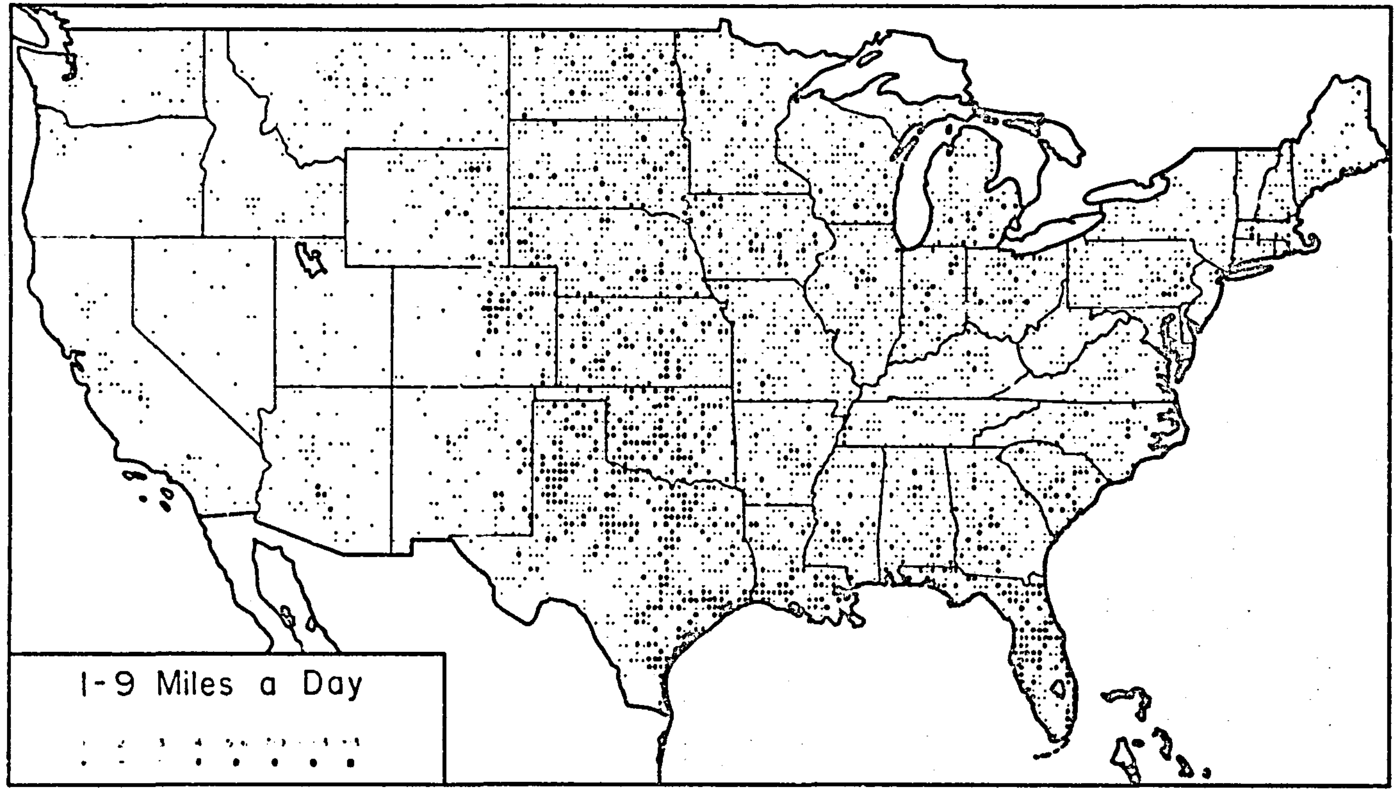


Fig. 6.9 Distribution of tornado occurrences on tornado days with 1 to 9 miles of combined path length per day (short path-length days).

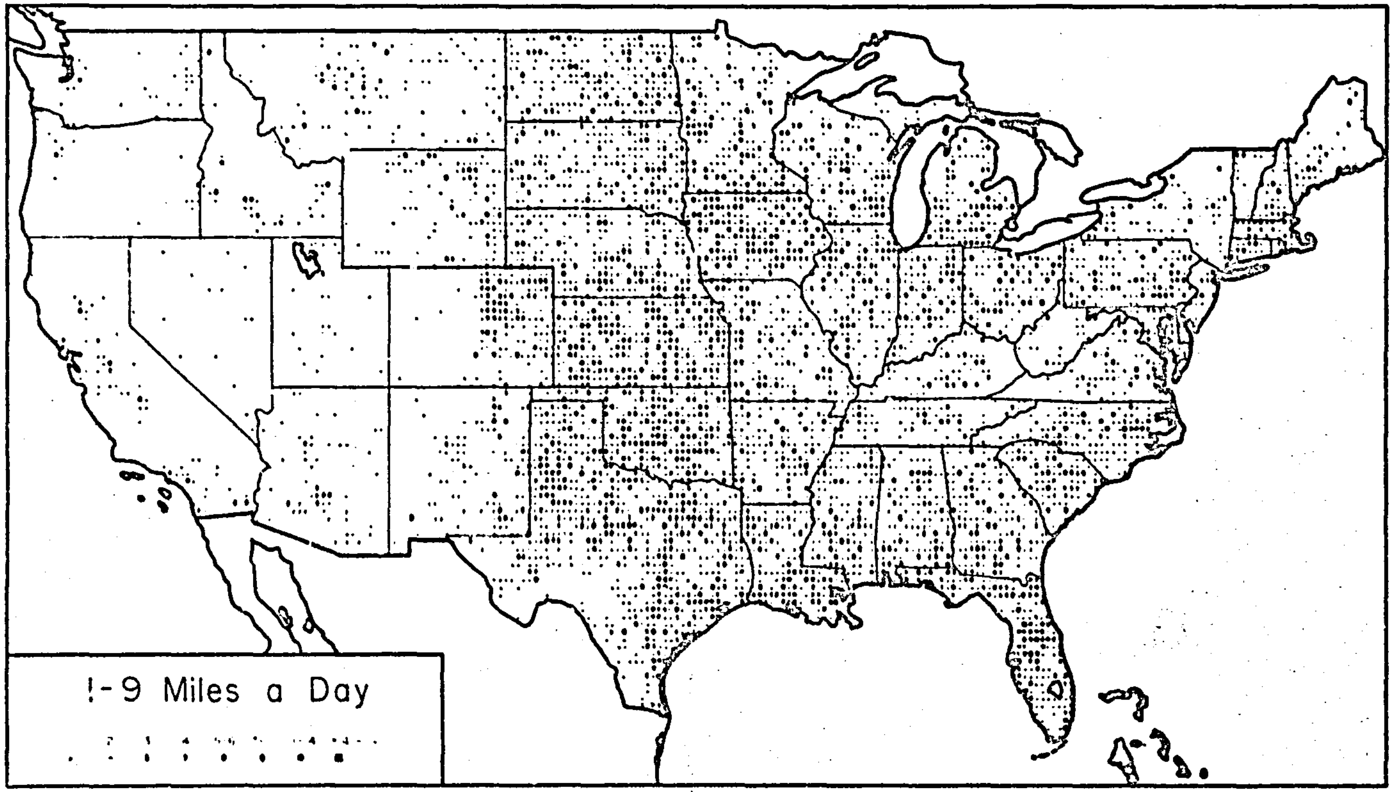


Fig. 6.10 Distribution of tornado path lengths on tornado days with 1 to 9 miles of combined path length per day (short path-length days).

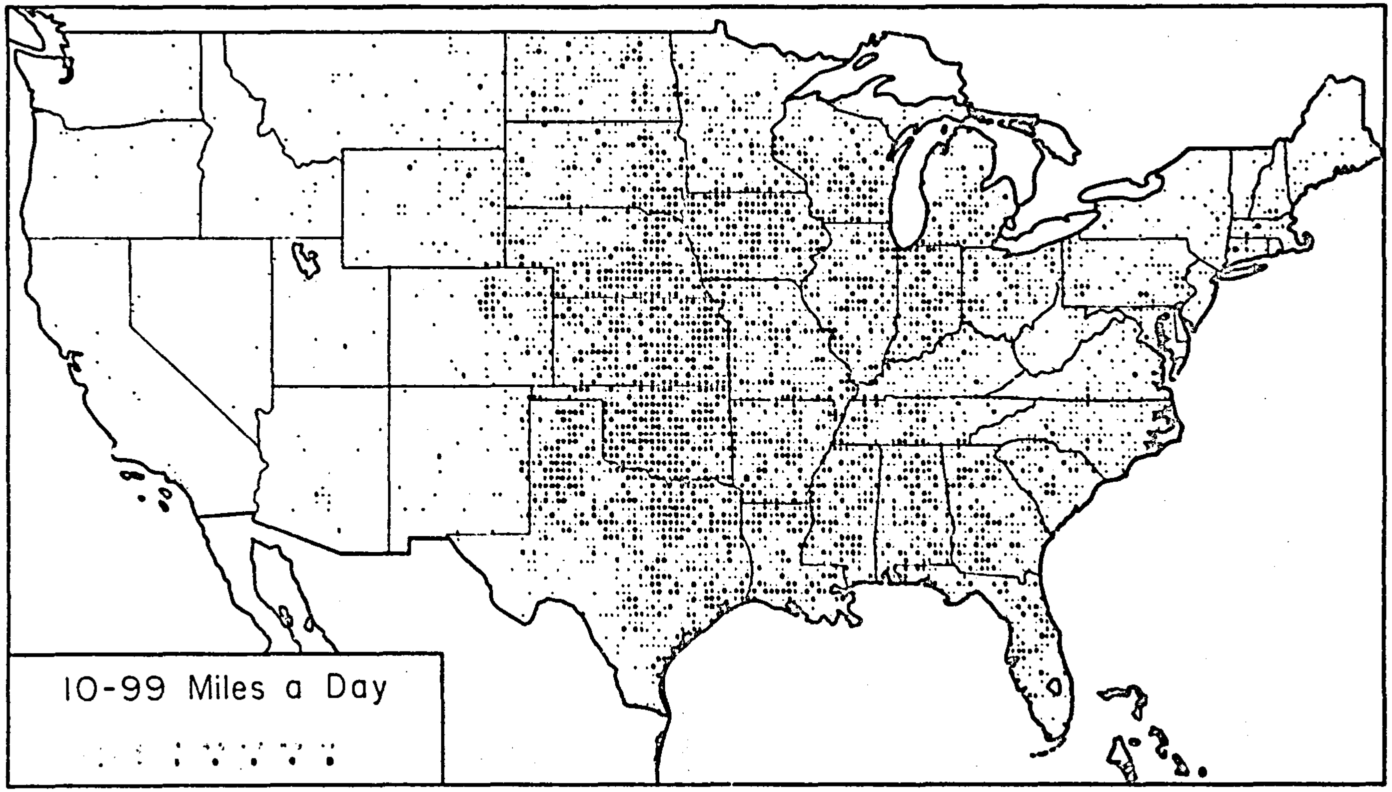


Fig. 6.11 Distribution of tornado occurrences on tornado days with 10 to 99 miles of combined path length per day (medium path-length days).

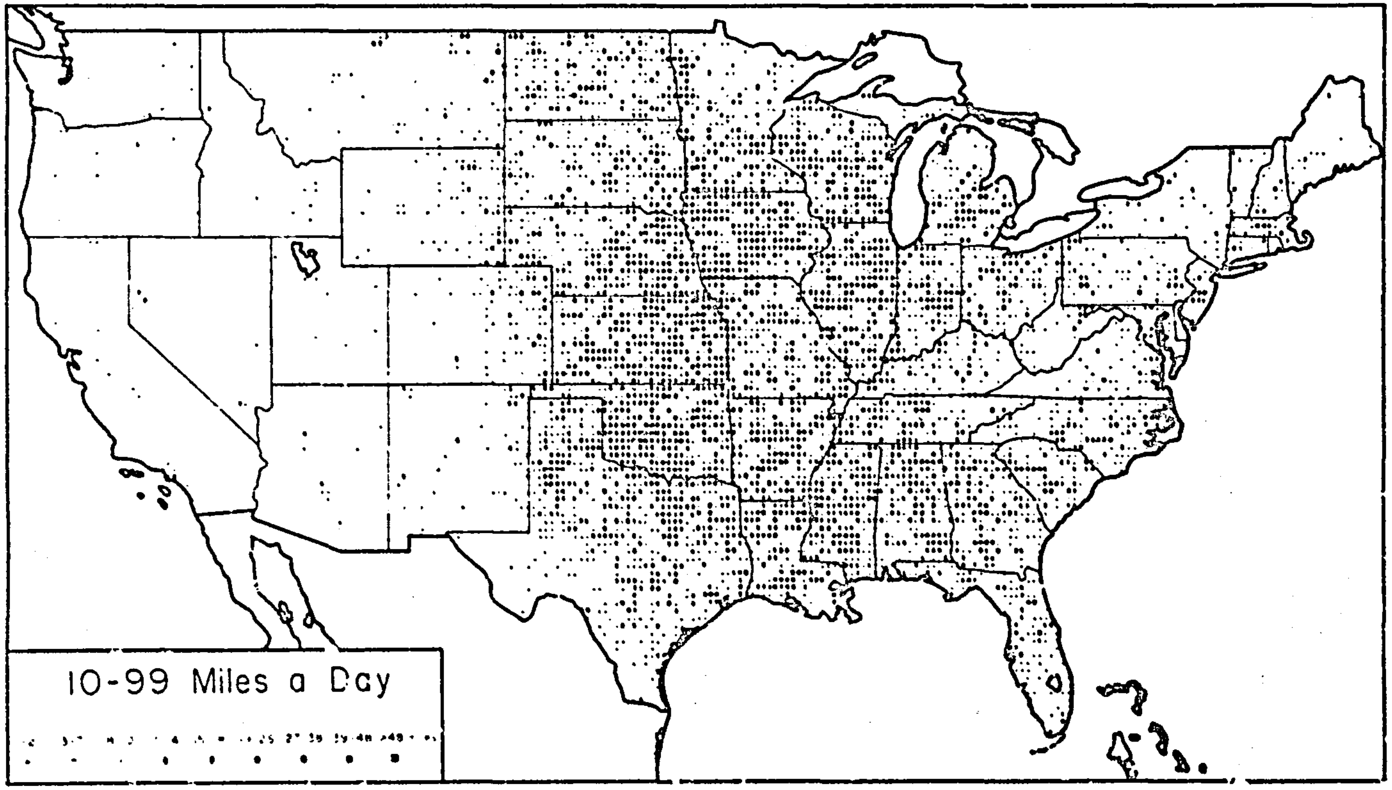


Fig. 6.12 Distribution of tornado path lengths on tornado days with 10 to 99 miles of combined path length per day (medium path-length days).

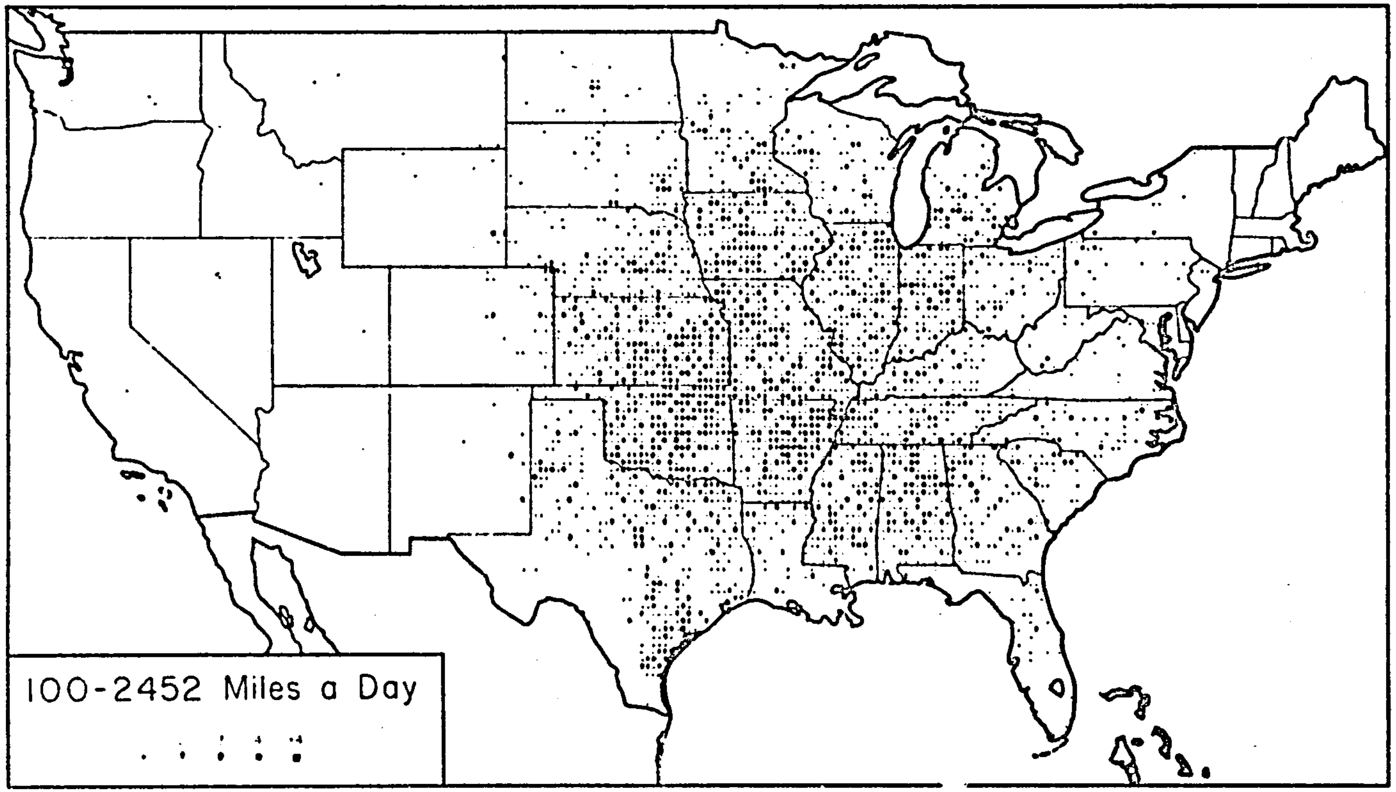


Fig. 6.13 Distribution of tornado occurrences on tornado days with over 100 miles of combined path length per day (long path-length days).

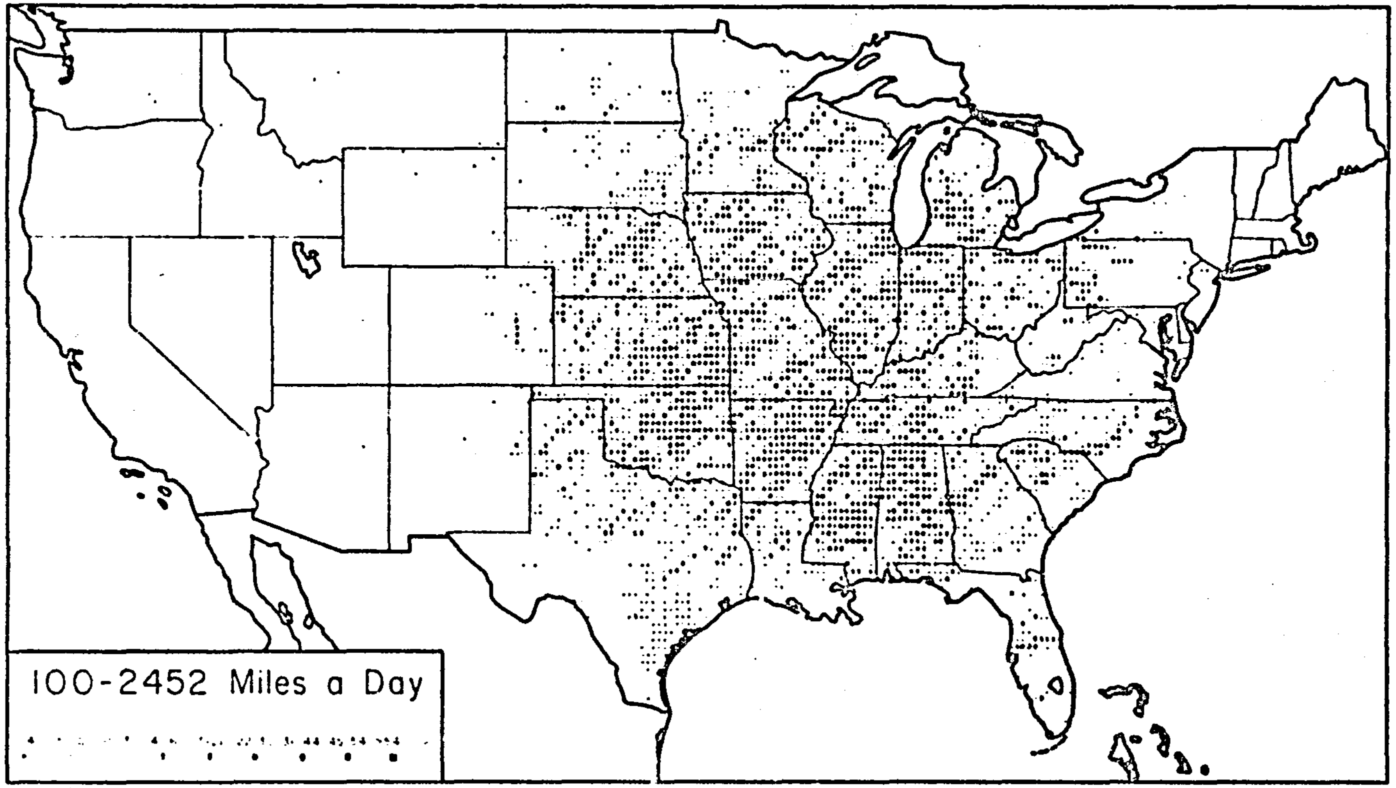
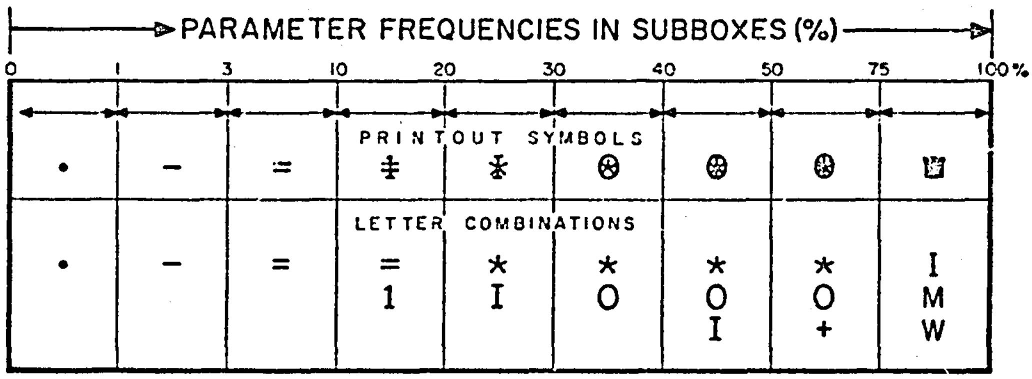


Fig. 6.14 Distribution of tornado path lengths on tornado days with over 100 miles of combined path length per day (long path-length days).

●●● OVERPRINT COMBINATIONS ●●●

The following letter combinations were used in generating the nine (9) printout symbols used in characterizing individual subboxes on the grid-print maps in this book. All quantities in subboxes were prorated by the inverse of the subbox area before computing parameter frequencies in generating the grid-print maps.



Chapter Seven

Maps by Direction of Motion

The motion of tornadoes is affected by the parent clouds which spawn them. On the other hand, parent clouds are steered by the weather system in which they are embedded. During the mature stage, the tornado axis is more or less vertical. Before reaching the dissipating stage, some tornadoes turn into rope funnels which are left way behind the parent clouds.

7.1 Statistical Direction of Motion

The motion of tornadoes are predominantly from the southwesterly direction. Of the 17,081 tornadoes of known direction during the 70 years, 10,117 (59%) moved from the southwest. Table 7.1 also reveals that 61 (72%) of all F5 tornadoes moved from the southwest.

Some tornadoes move from the west or northwest, because some convective clouds are steered by the westerly to northwesterly winds. It should also be noted that rotating clouds, which often spawn tornadoes, tend to deviate to the right of the steering winds by as much as 45° to 60°.

Figure 7.1 was constructed from Table 7.1 by separating tornadoes into weak (F0+F1), strong (F2+F3), and violent (F4+F5) categories. By and large, the southwest is the direction to look for destructive tornadoes when a tornado watch or a tornado warning is in effect.

Table 7.1 Direction of motion of tornadoes in 70 years, 1916-1985, tabulated by eight-point directions. IND denotes individual F scales and CUM, cumulative occurrences of a specific F scale or stronger tornadoes.

IND	N	NE	E	SE	S	SW	W	NW
F5	1	0	0	0	2	61	17	4
F4	2	2	1	3	35	433	89	47
F3	22	16	6	43	119	1578	407	208
F2	52	48	26	120	294	3493	1008	599
F1	90	67	58	163	329	3282	1138	732
F0	51	42	40	78	166	1270	520	319

CUM	N	NE	E	SE	S	SW	W	NW
F5	1	0	0	0	2	61	17	4
F4+	3	2	1	3	37	494	106	51
F3+	25	18	7	46	156	2072	513	259
F2+	77	66	33	166	450	5565	1521	858
F1+	167	133	91	329	779	8847	2659	1590
F0+	218	175	131	407	945	10117	3179	1909

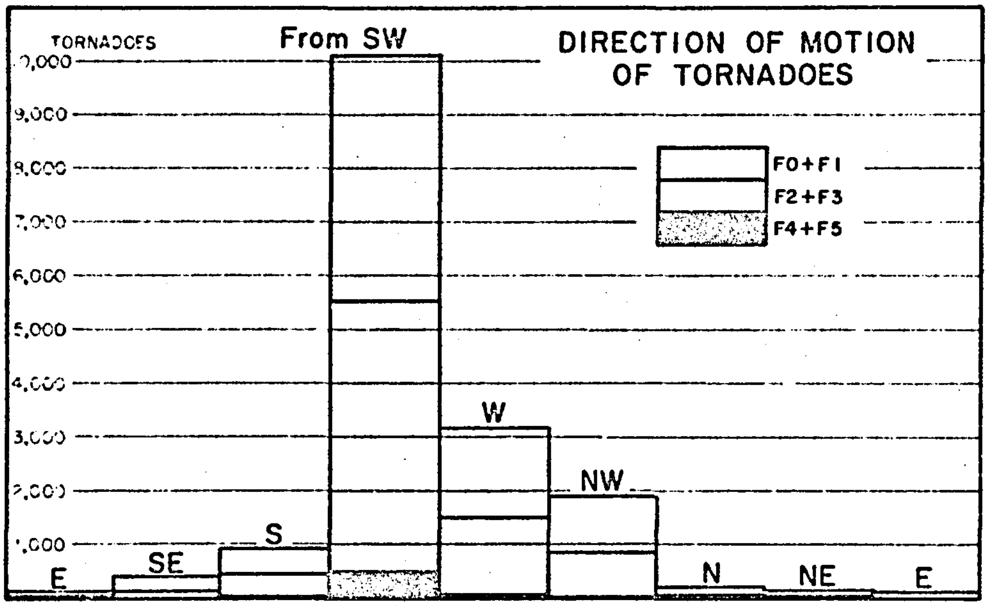


Fig. 7.1 Bar-graph presentation of the direction of motion of tornadoes shown in Table 7.1.

7.2 Distribution by Direction of Motion

Geographic distributions of tornadoes which moved from the eight-point directions are presented in Figs. 7.2 through 7.17. As in other grid-print maps, tornado occurrences are presented in blue and tornado path lengths in red.

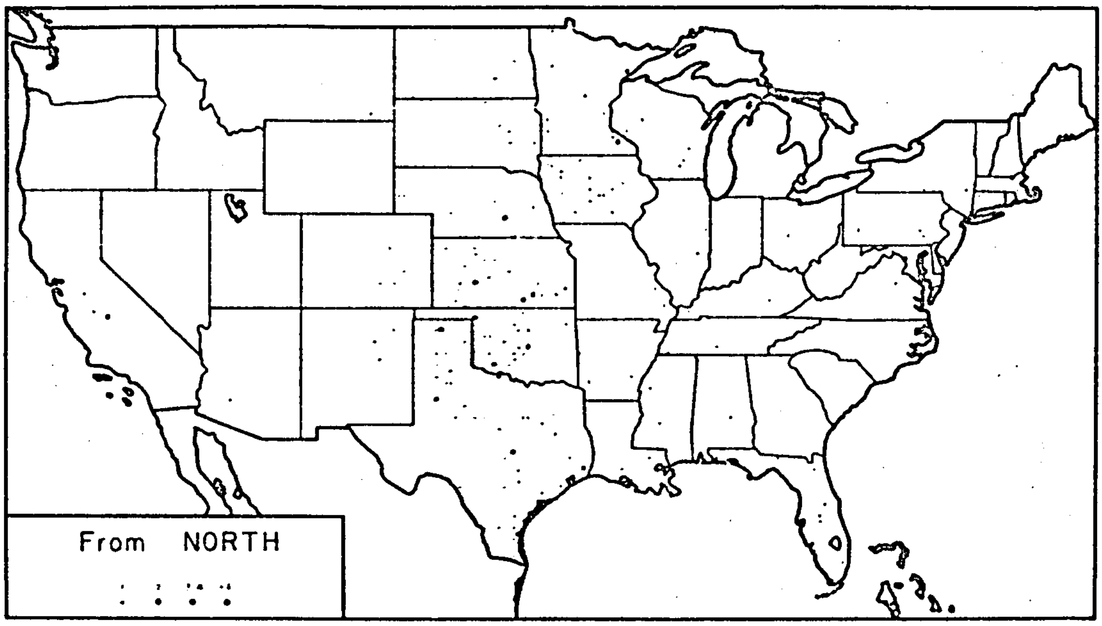


Fig. 7.2 Occurrences of tornadoes which moved from the north.

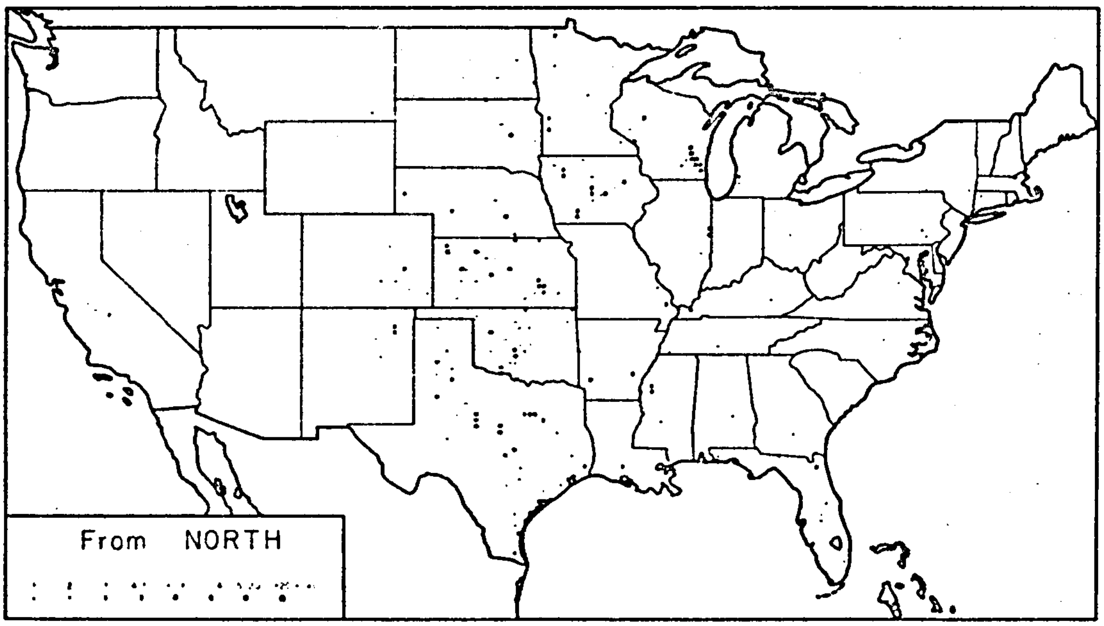


Fig. 7.3 Path lengths of tornadoes which moved from the north.

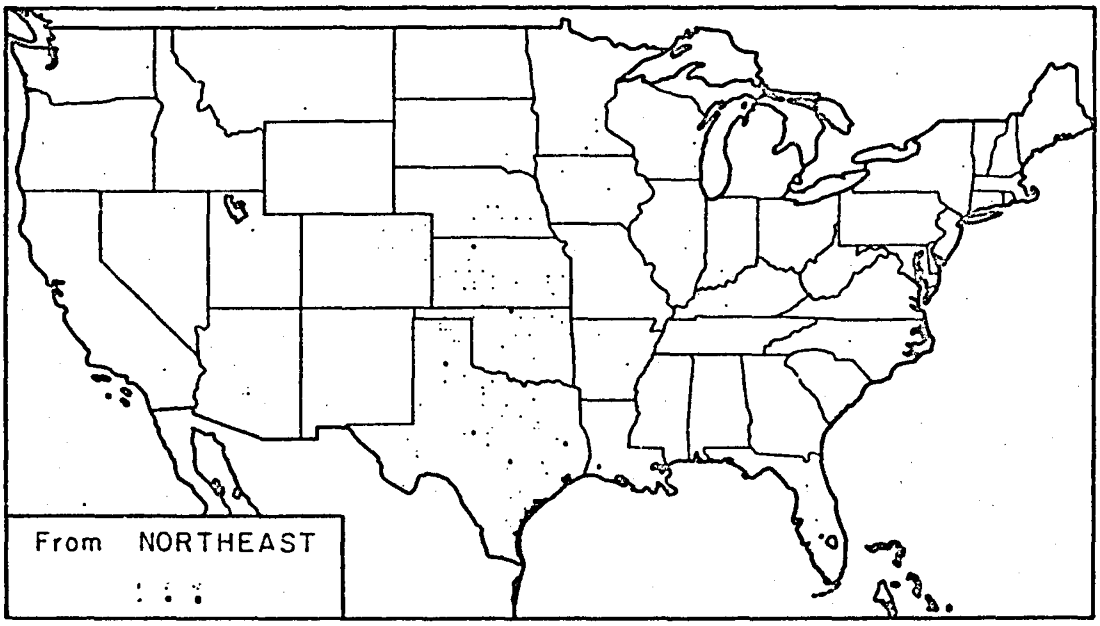


Fig. 7.4 Occurrences of tornadoes which moved from the northeast.

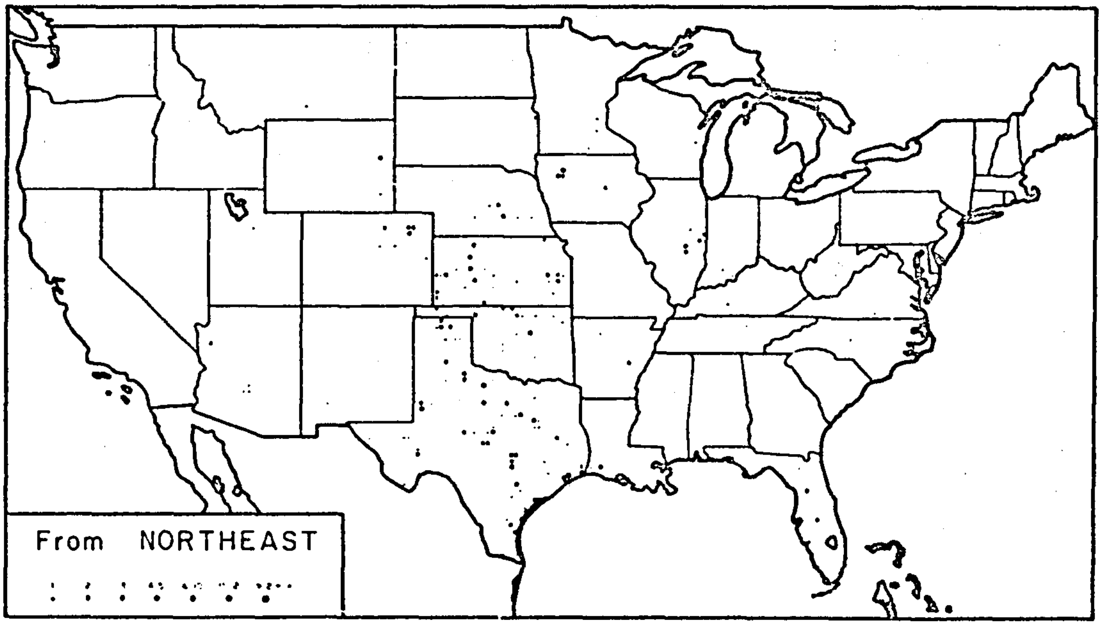


Fig. 7.5 Path lengths of tornadoes which moved from the northeast.

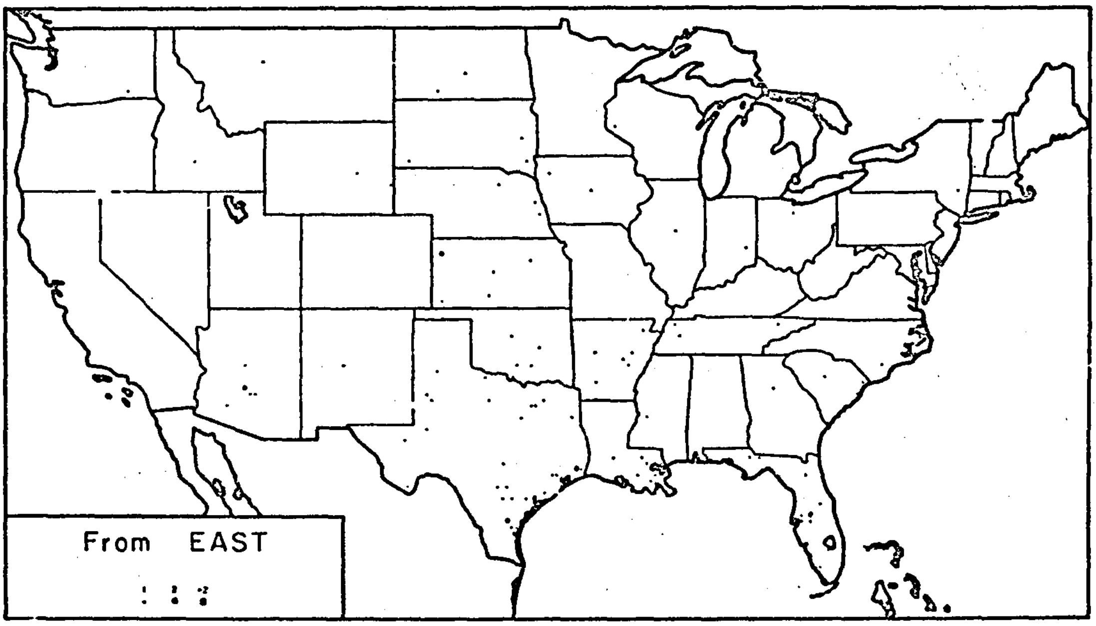


Fig. 7.6 Occurrences of tornadoes which moved from the east.

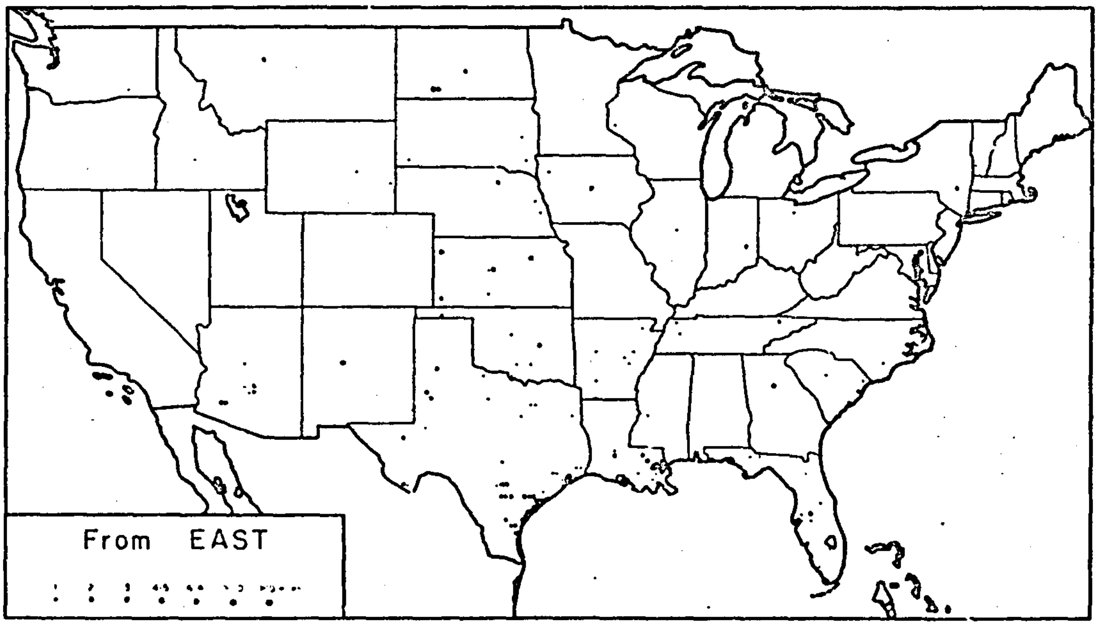


Fig. 7.7 Path lengths of tornadoes which moved from the east.

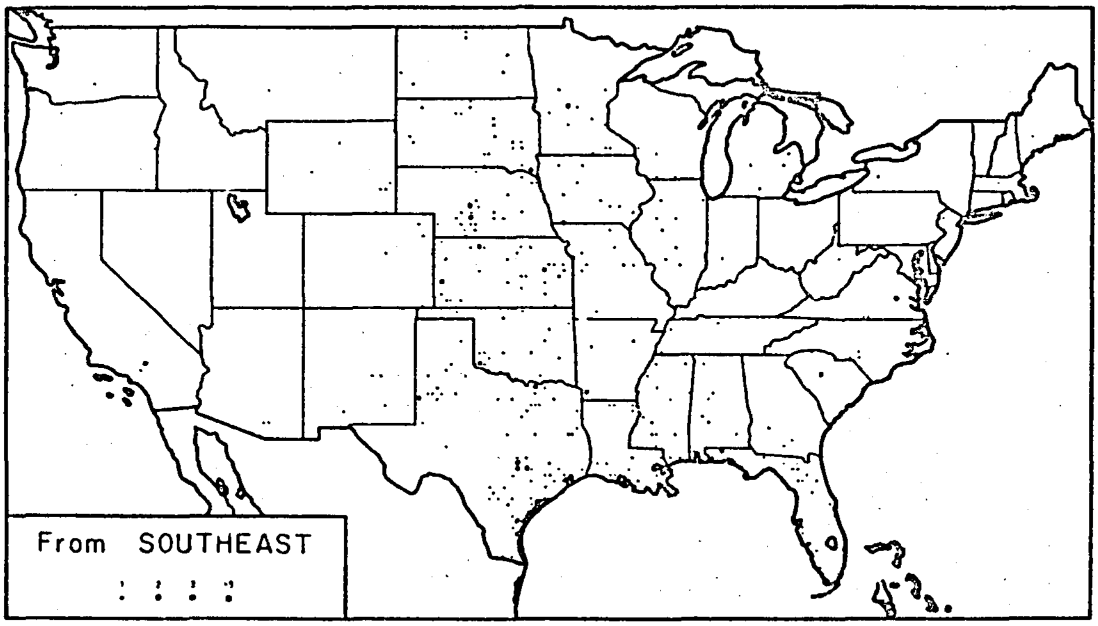


Fig. 7.8 Occurrences of tornadoes which moved from the southeast.

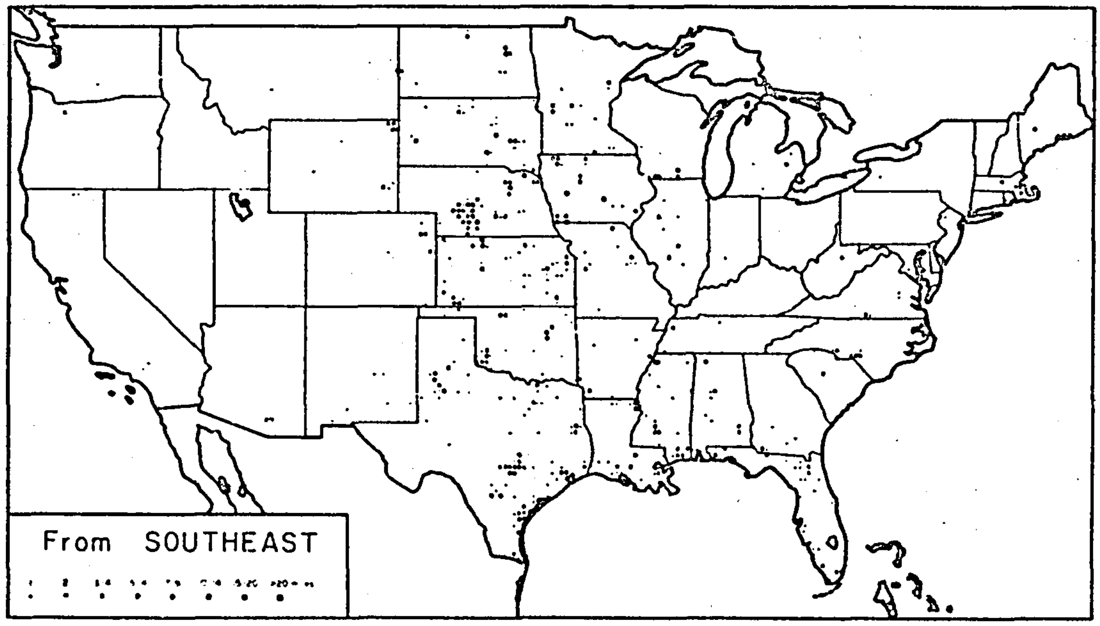


Fig. 7.9 Path lengths of tornadoes which moved from the southeast.

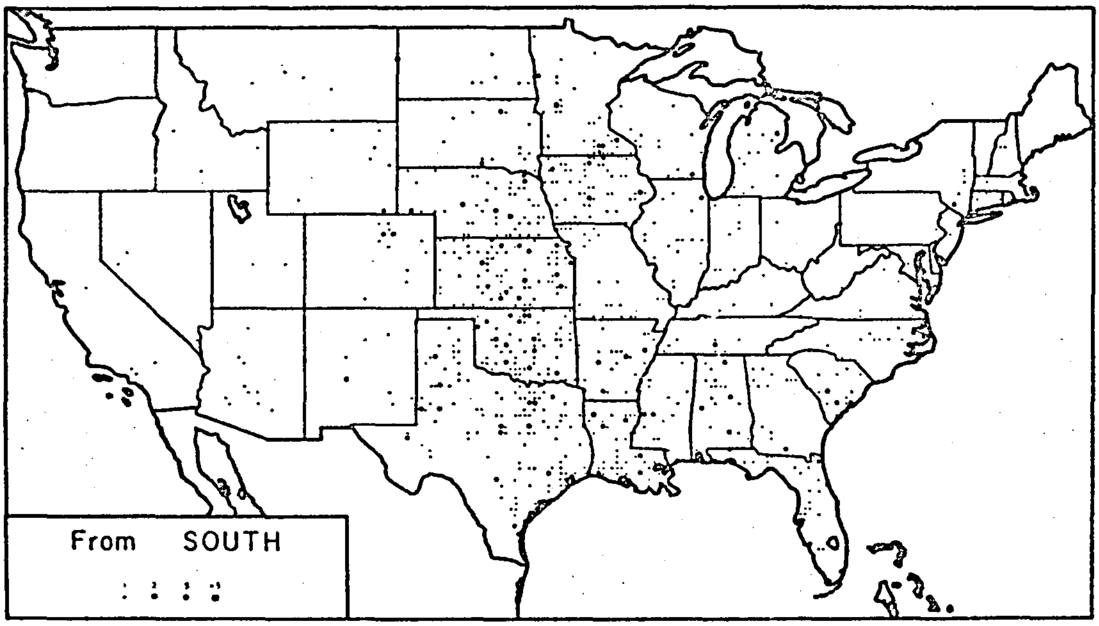


Fig. 7.10 Occurrences of tornadoes which moved from the south.

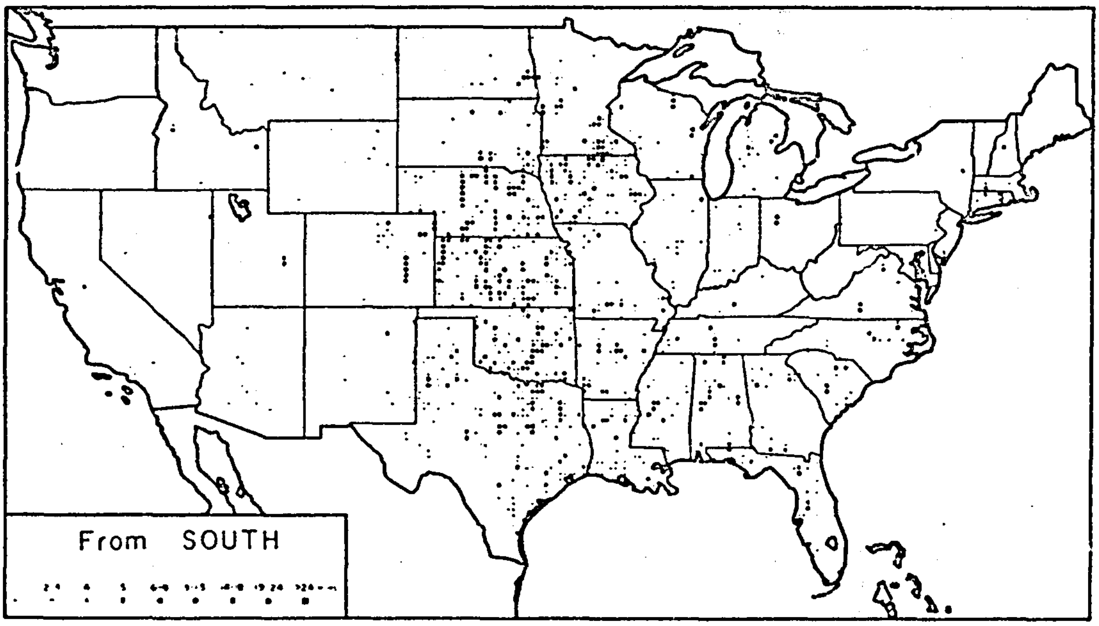


Fig. 7.11 Path lengths of tornadoes which moved from the south.

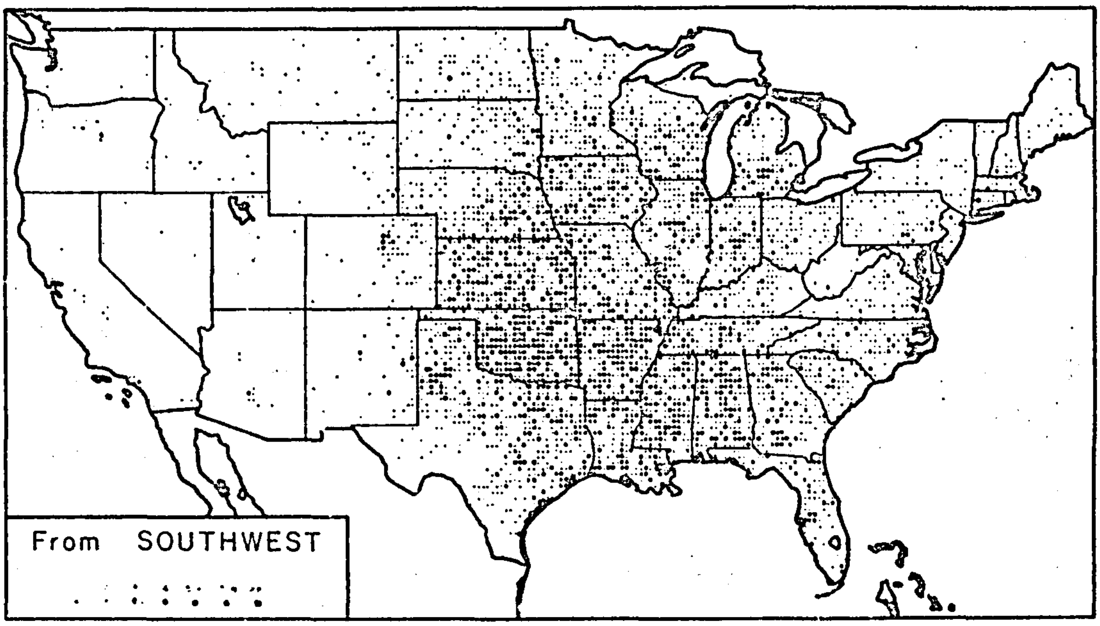


Fig. 7.12 Occurrences of tornadoes which moved from the southwest.

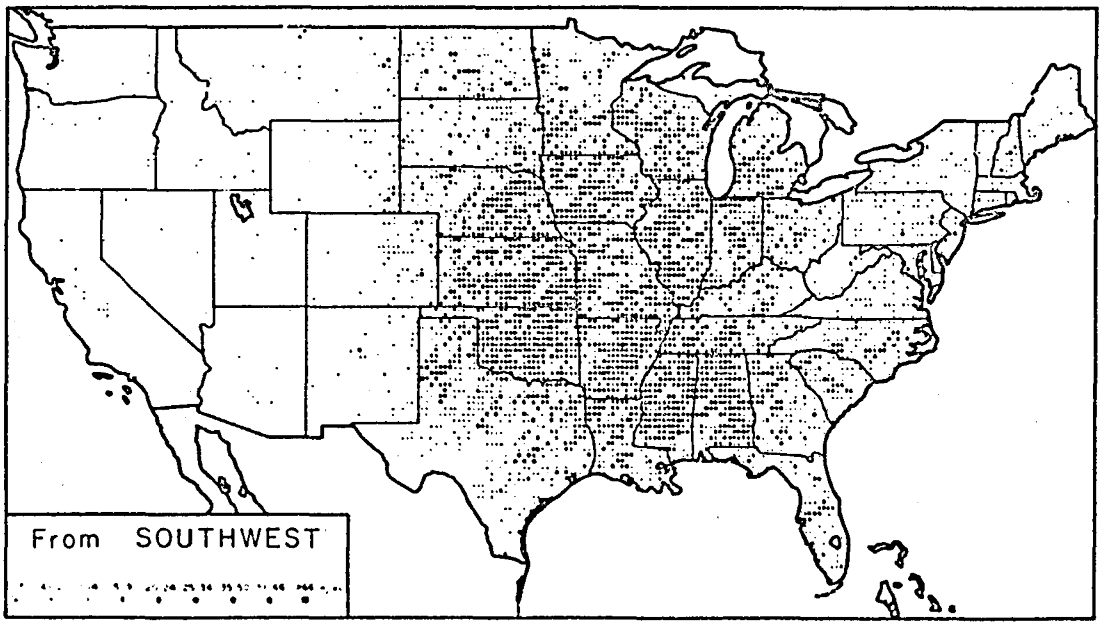


Fig. 7.13 Path lengths of tornadoes which moved from the southwest.

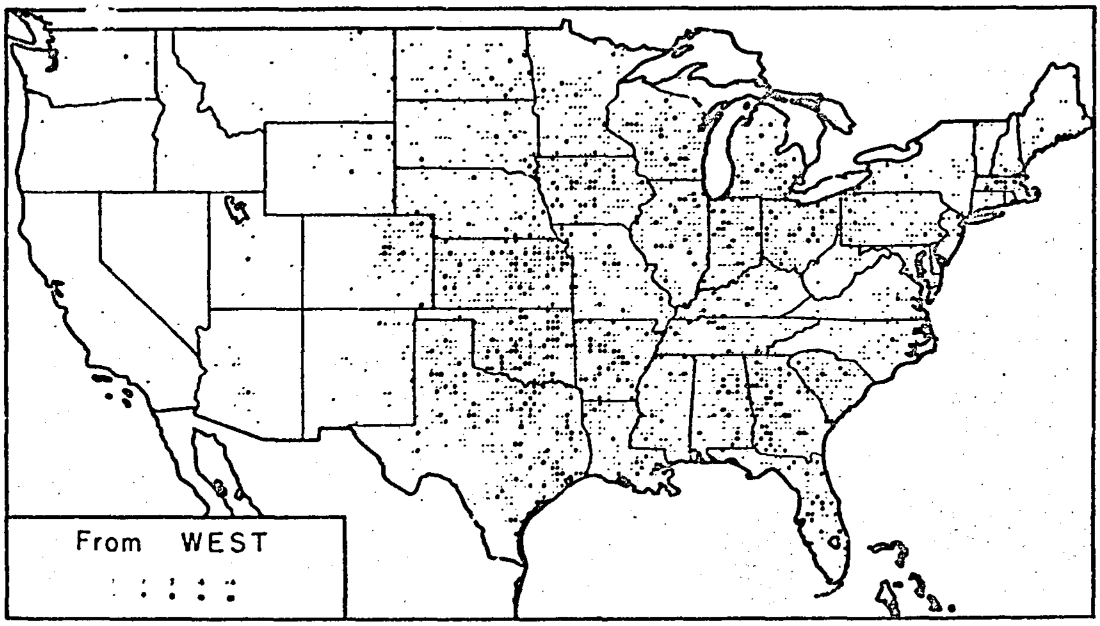


Fig. 7.14 Occurrences of tornadoes which moved from the west.

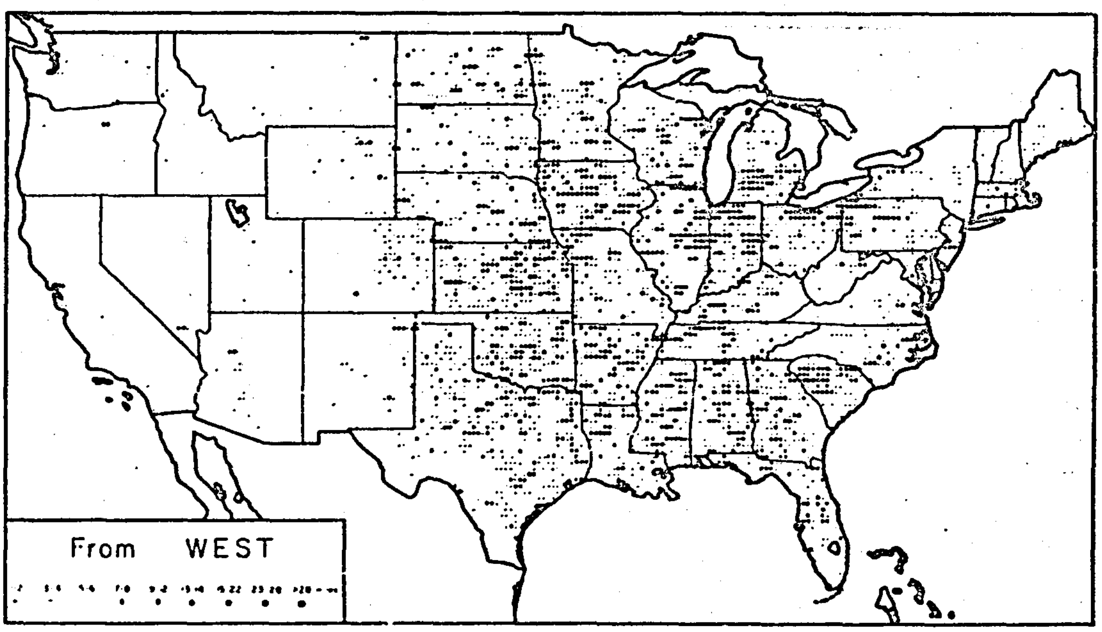


Fig. 7.15 Path lengths of tornadoes which moved from the west.

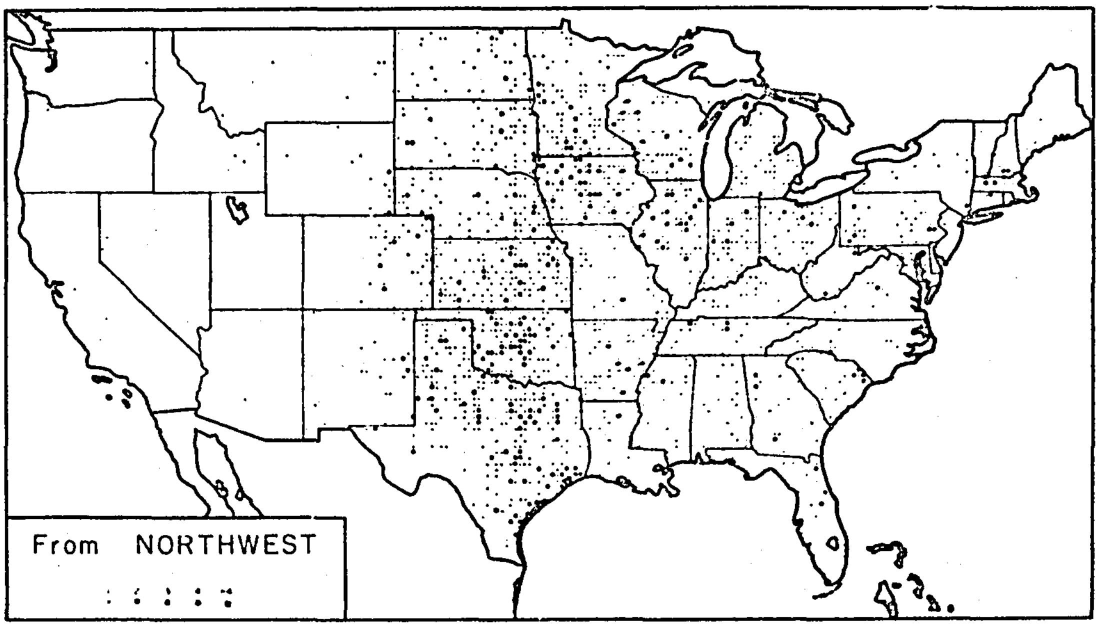


Fig. 7.16 Occurrences of tornadoes which moved from the northwest.

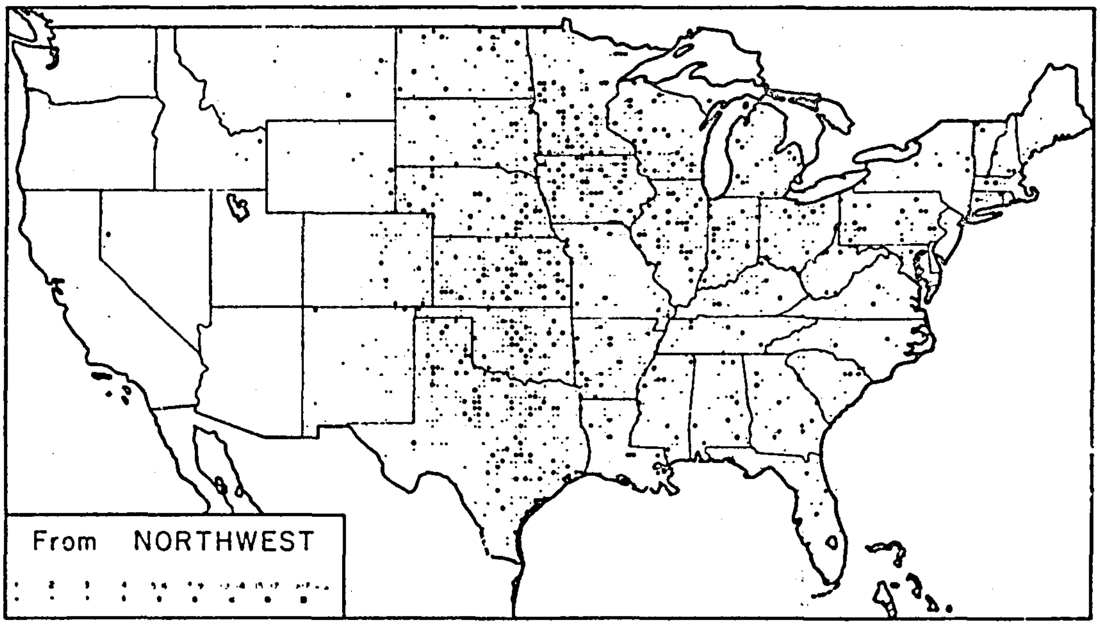


Fig. 7.17 Path lengths of tornadoes which moved from the northwest.

Chapter Eight

Tornado Windspeed by Probability

by Robert F. Abbey Jr. and T. Theodore Fujita

Although it is common knowledge that tornadoes along the West Coast are significantly weaker than those in the Midwestern states, many people want estimates of regionalized maximum windspeeds of tornadoes expected to occur in various parts of the United States.

We know that once-in-a-century tornadoes are far worse than the garden-variety tornadoes experienced rather frequently. Therefore, it is necessary to specify the occurrence probability in computing the maximum windspeed of a given weather disturbance such as the tornado. In fact, nuclear power plants in the United States are required to be protected against the fury of the 10^{-7} (1/10,000,000) per year tornadoes.

8.1 Tornado Probability

The period of reliable tornado data collection in the contiguous United States is only 70 years beginning in 1916. If one were to operate an anemometer at a fixed location continuously during this period, it would barely record a once-in-a-century tornado. In computing probabilities of tornadoes, such as 10^{-3} , 10^{-4} , ... per year, we have to use other methods of probability computations, because our statistical years are not long enough.

As long as one stays at a fixed location, he may not be able to experience the once-in-1000-year tornado during his lifetime. However, by moving around the country in search of tornado damage after each storm, there are good chances to find extreme tornado damage in very small areas. In general, the worse the damage, the smaller the damage area.

Based on this concept, the tornado probability of a given windspeed V within a given area can be computed from

$$P_{(V)} = \frac{\sum a_{(V)}}{A} / Y \qquad \text{(per year)} \tag{1}$$

where $P_{(V)}$ denotes the probability of V mph windspeed, $a_{(V)}$ the area of V mph windspeed inside the statistical area A and during the statistical year Y.

8.2 DAPPL Values and Windspeed Areas

It is desirable to use the University of Chicago Tornado Tape for computing $a_{(V)}$ in Eq. (1). Although the tape contains F scales and path lengths of all tornadoes, the path width data are limited. In an attempt to compute $a_{(V)}$ from F scale and path length, the only parameters available for all tornadoes, Abbey and Fujita (1975, 1979) developed the concept of the Damage Area Per Path Length (DAPPL) values.

$$DAPPL_{(V)} = \frac{a_{(V)}}{L} \qquad \text{(mile)} \tag{2}$$

As defined in Eq. (2), DAPPL is the damage area $a_{(V)}$ caused by V mph or stronger tornado windspeed divided by the path length. In other words, the DAPPL value is the mean width of the V mph area averaged over the path length.

Because we expect that the DAPPL value varies with windspeed and type of tornadoes, it can be expressed as a function of V and F scale. Based mainly on the well-surveyed data of the Superoutbreak Tornadoes of April 3-4, 1974, the following equations and constants were established.

$$\mathrm{DAPPL}_{(V)} = 10^{-xV^{y}} \qquad \text{(mile)} \qquad (3)$$

where x and y are constants in the following table:

F scale	F0	F1	F2	F3	F4	F5	
x	1245	676	361	192	105	56	$\times 10^{-6}$
y	1.290	1.300	1.323	1.360	1.477	1.552	

8.3 Computation and Maps of Maximum Windspeeds

In computing the maximum windspeed as a function of occurrence probability, the area of each subbox was used in determining L_1, L_2, ..., L_5; the path length left behind by F0, F1, ..., F5 tornadoes, respectively. Then the combined probability of all tornadoes in each subbox was obtained by adding the individual probabilities of F0, F1, ..., F5 tornadoes.

The determination of the maximum windspeed in each subbox was achieved by increasing the windspeed V in 10 mph steps from 0 mph up to the maximum windspeed at which the total probability becomes equal to or smaller than the specified probability, 10^{-3}, 10^{-4}, ... etc. The maximum windspeed computed for each subbox was stored in memory for computing the smoothed value within each of the 5 x 5 = 25 subboxes centered at every single subbox. Figs 8.1 through 8.5 present the windspeed distributions corresponding to the 10^{-3} to 10^{-7} per year probabilities.

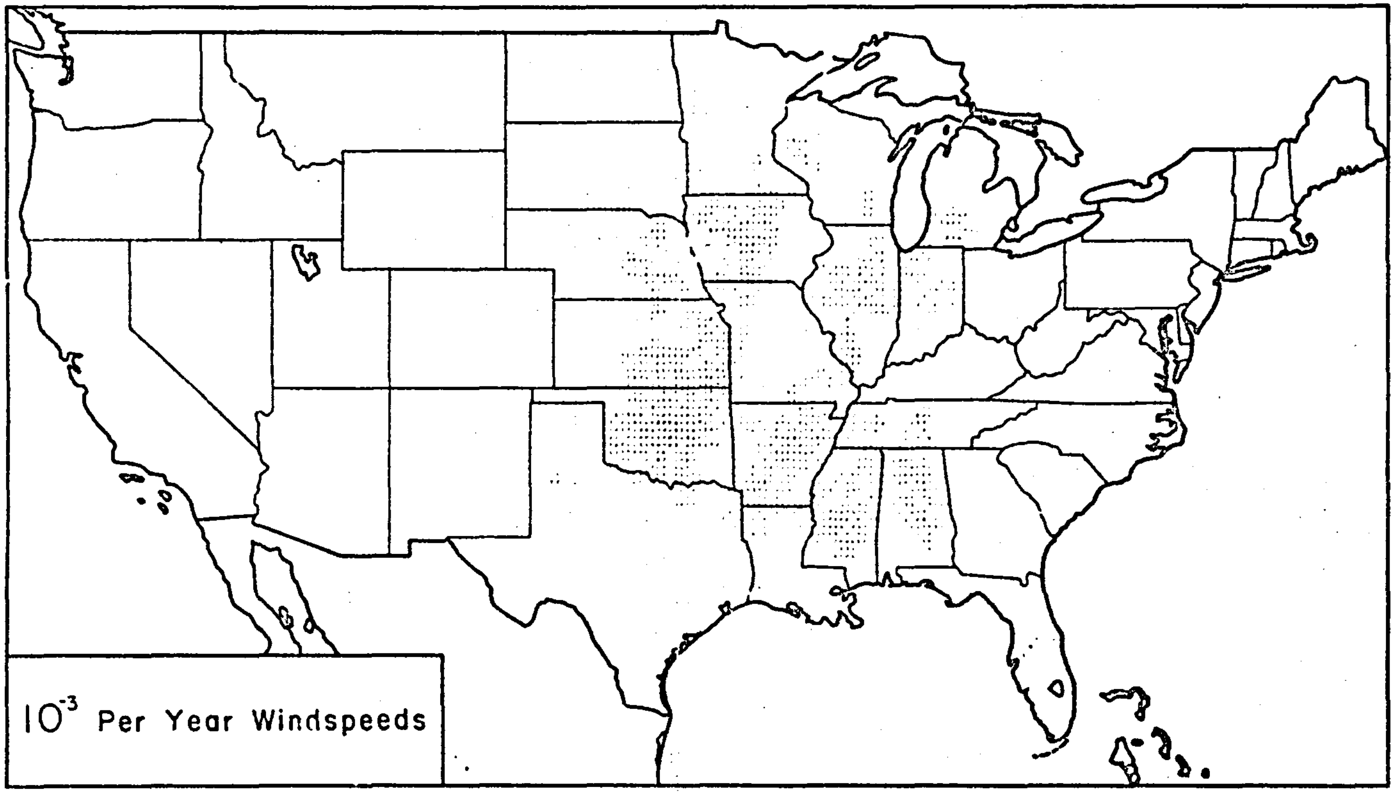


Fig. 8.1 Distribution of the maximum windspeeds of tornadoes expected to occur with a 10^{-3} per year probability. Windspeed ranges are: Green (less than 100 mph). Within the same color, windspeeds increase as the density of the symbols in the subboxes increases.

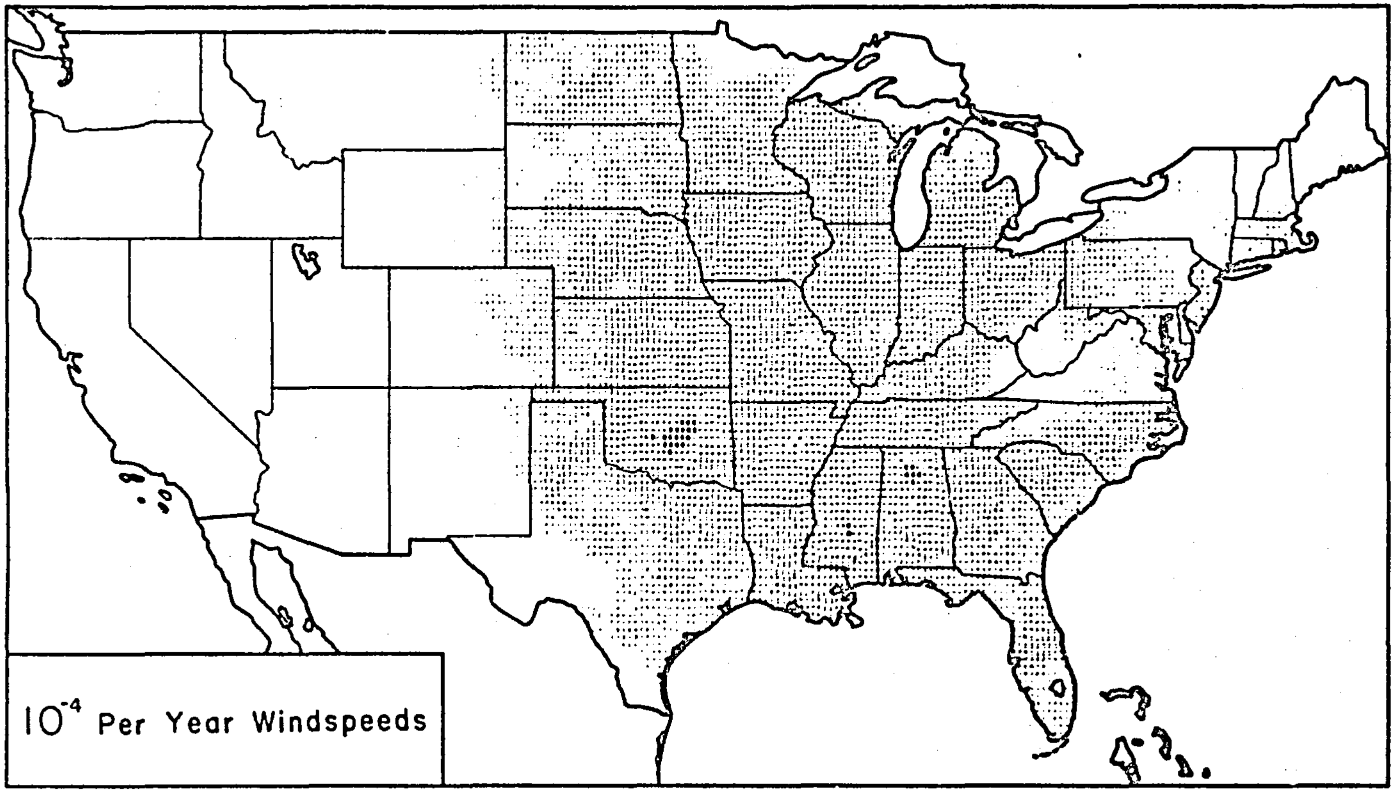


Fig. 8.2 Distribution of the maximum windspeeds of tornadoes expected to occur with a 10^{-4} per year probability. Windspeed ranges are: Green (less than 100 mph), and Blue (100 mph or greater but less than 200 mph).

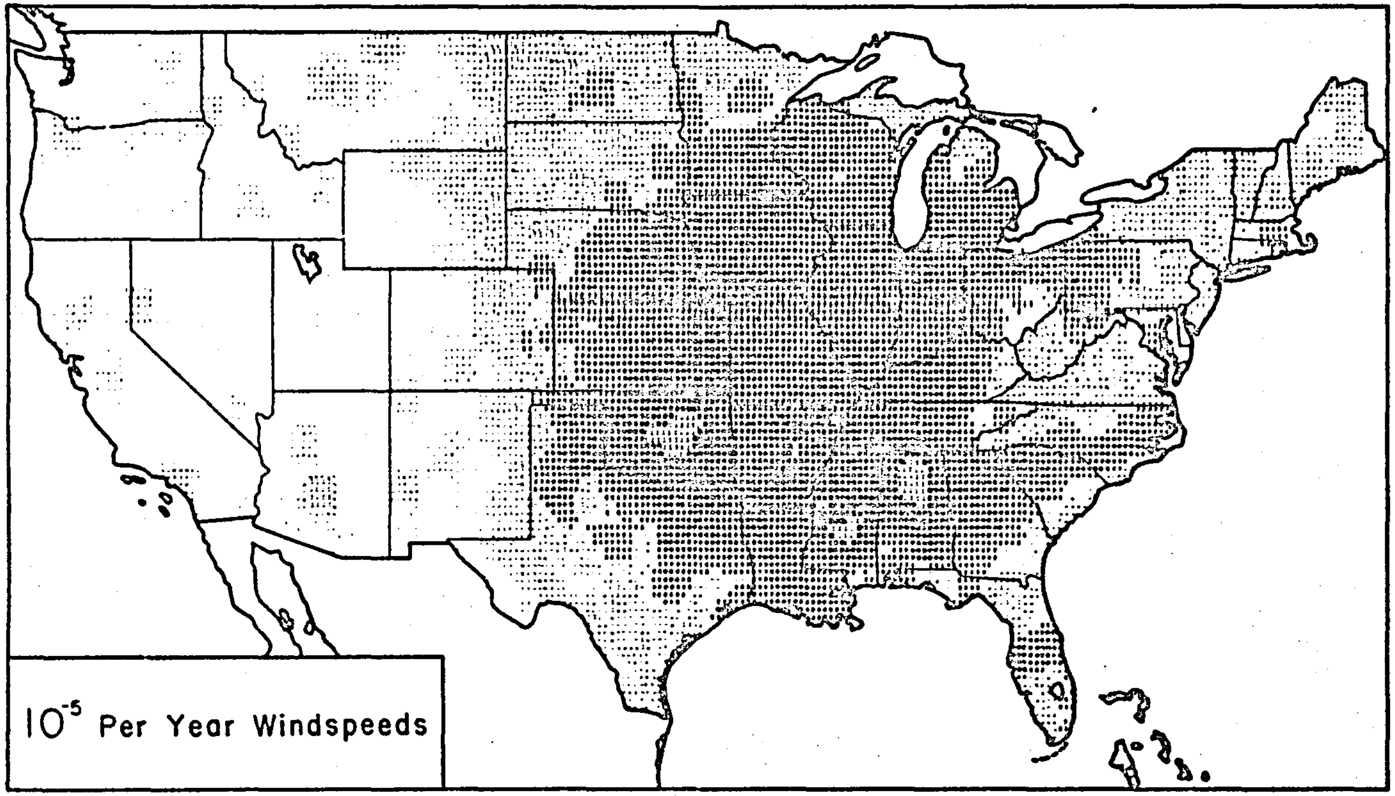


Fig. 8.3 Distribution of the maximum windspeeds of tornadoes expected to occur with a 10^{-5} per year probability. Windspeed ranges are: Green (less than 100 mph), Blue (100 mph or greater but less than 200 mph), and Brown (200 mph or greater but less than 300 mph).

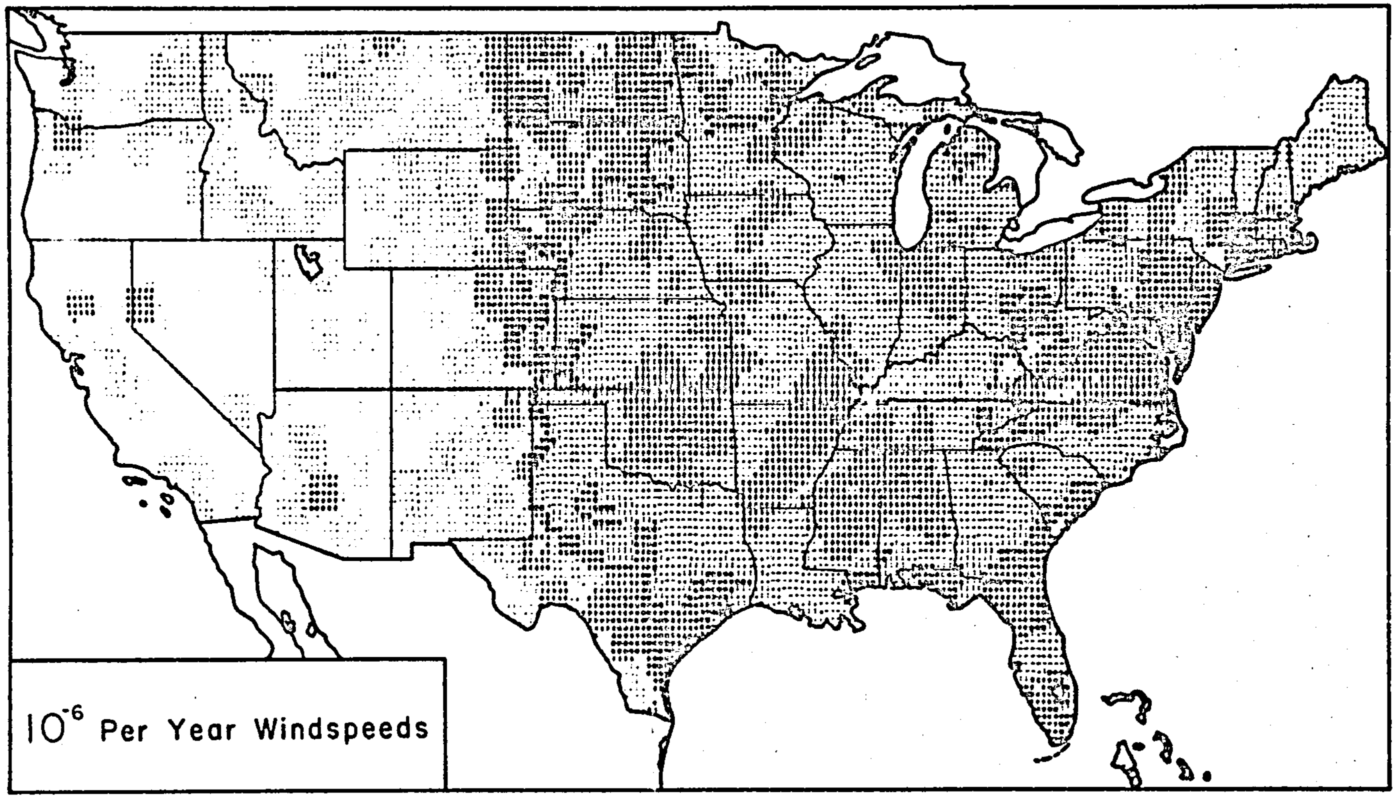


Fig. 8.4 Distribution of the maximum windspeeds of tornadoes expected to occur with a 10^{-6} per year probability. Windspeed ranges are: Green (less than 100 mph), Blue (100 mph or greater but less than 200 mph), and Brown (200 mph or greater but less than 300 mph).

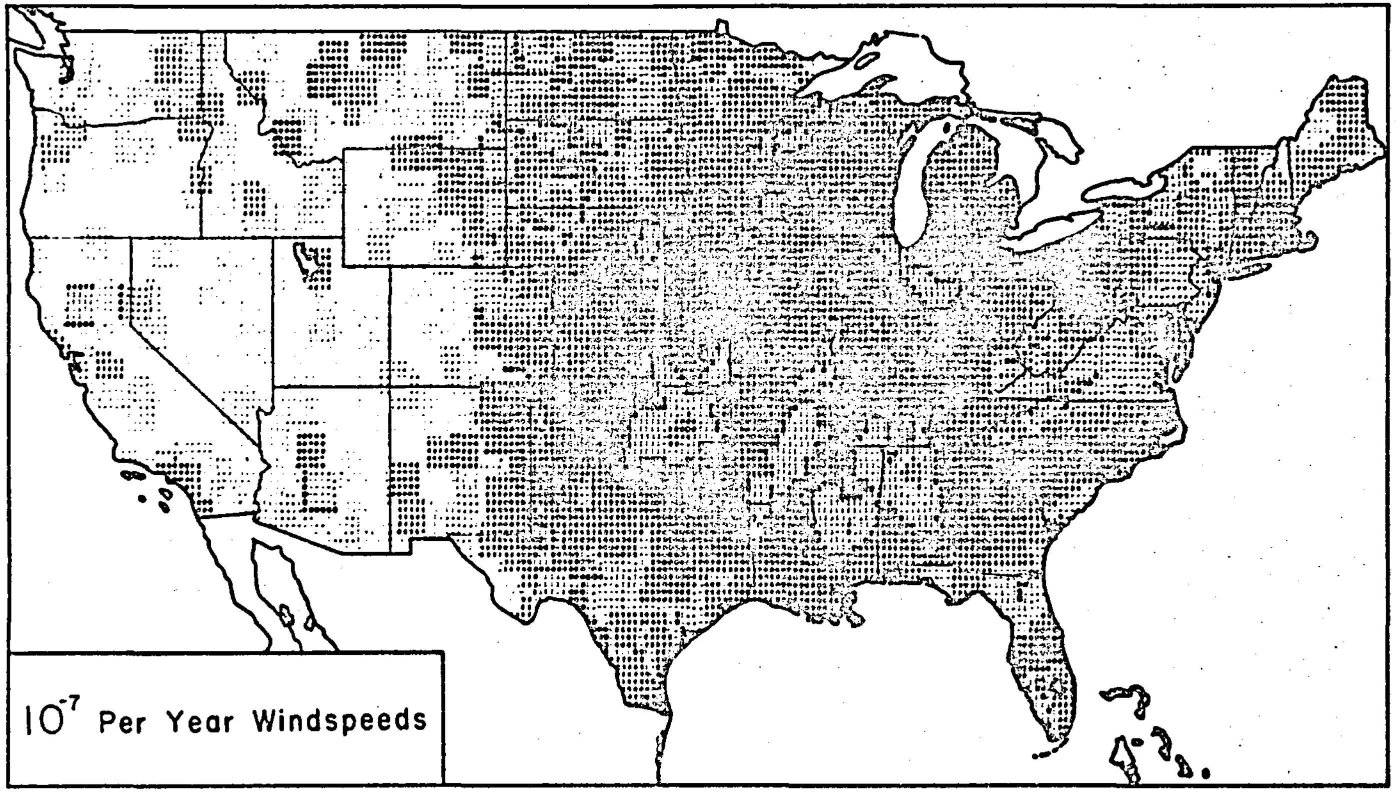


Fig. 8.5 Distribution of the maximum windspeeds of tornadoes expected to occur with a 10^{-7} or 1/10,000,000 per year probability which is required for protecting nuclear power plants in the United States. Windspeed ranges above 200 mph are: Brown (200 mph or greater but less than 300 mph), and Red (300 mph or greater but less than 309 mph).

Summary and Conclusions

In spite of the eagerness of dedicated individuals at National Weather Service stations all around the country, the collection of the tornado data at the national level has been endangered several times, due mainly to budgetary problems in recent years. In view of uncertainties in the data-collection program, the author decided to undertake extensive statistical analyses of U.S. tornadoes at the conclusion of the 70th year of the data collection.

The University of Chicago Tornado Tape, 1916 to 1985, contains various characteristics of 31,054 tornadoes confirmed during the 70-year period ending December 31, 1985. The tape was used in determining long-term, seasonal, and diurnal variations of tornadoes. Tornadoes were also sorted by their direction of motion and other parameters in an ultimate attempt to generate a large number of grid-print maps in color.

Finally, the maximum windspeeds of tornadoes were mapped as a function of occurrence probabilities ranging from 10^{-3} to 10^{-7} per year. The highest windspeed of 308 mph with a 10^{-7} per year probability was found to be located in both central Oklahoma and northern Alabama.

Statistics of tornado activities presented in this book will be useful in assessing tornado hazards in various parts of the country. However, the longer the statistical period, the more reliable the results. The author sincerely hopes that the data collection at the national level will continue in future years so that our successors can make the most of the long-term statistics available only in the United States.

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